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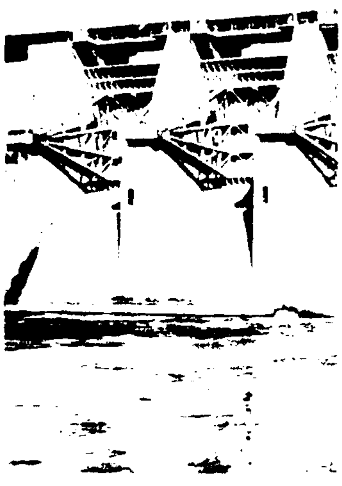

ENVIRONMENTAL IMPACT
RESEARCH PROGRAM

INTERDISCIPLINARY WORKSHOP ON THE PHYSICAL-CHEMICAL-BIOLOGICAL PROCESSES AFFECTING ARCHEOLOGICAL SITES

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January 1989

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Contract No. DACW39-86-K-0016

Monitored by Environmental Laboratory
US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39181-0631

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) Contract Report EL-89-1
6a. NAME OF PERFORMING ORGANIZATION Texas A&M University Department of Geology 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USAEWES Environmental Laboratory
6c. ADDRESS (City, State, and ZIP Code) College Station, TX 77843-3115	7b. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 31981-0631
8a. NAME OF FUNDING / SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. DACW39-86-K-0016
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Interdisciplinary Workshop on the Physical-Chemical-Biological Processes Affecting Archeological Sites

12. PERSONAL AUTHOR(S)
Mathewson, Christopher C., Editor

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM ____ TO ____	January 1989	305

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17 COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Archeological site preservation Site burial Site decay processes

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

To date, the impact of burial upon archeological site components is largely unknown. This interdisciplinary workshop was organized to summarize the state of existing knowledge in the variety of relevant disciplines to provide a basis for future research.

Archeological sites are assemblages of components with a geographic relationship. Components include bone, shell, plant remains, charcoal, crystalline and granular lithics, ceramics, and metal artifacts. Geographic relationships include soil and stratigraphic attributes, site micro-topography, general site context, and archeological features.

The workshop concluded that each of these components and geographic relationships reacts differently to changes in the physical, biological, and chemical environment

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20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

19. ABSTRACT (Continued).

surrounding the site. Whereas basic scientific data are lacking to develop a quantitative site decay model, the workshop was able to develop a qualitative site decay matrix for the differing components. Further, it was concluded that any attempts to achieve site preservation by means of burial should be carried out as cooperative effort between the engineer, geologist, and archeologist.

PREFACE

The information compiled in this report was collected under SFRC No. DACW39-86-K-0016, issued by the US Army Engineer Waterways Experiment Station (WES) to the Texas A&M Research Foundation, to hold an interdisciplinary workshop on the physical-chemical-biological processes affecting archaeological* sites to develop an archaeological site decay model. This workshop was initiated in response to Topic No. EL-15, Conservation of Archaeological Sites, listed in the WES's Broad Agency Announcement, October 1985.

This work was performed at the Center for Engineering Geosciences, Texas A&M University, College Station, TX, under an agreement between the Texas A&M University System and the Texas A&M Research Foundation, under Research Foundation Project No. 5599000 (RF 86-973). The project was assigned to the Department of Geology at Texas A&M University, which designated Dr. Christopher C. Mathewson, Director of the Center for Engineering Geosciences, to be Project Supervisor.

The contract was monitored by Dr. F. Douglas Shields of the Water Resources Engineering Group, Environmental Engineering Division (EED), Environmental Laboratory (EL) WES, and it was performed under auspices of the Environmental Impact Research Program (EIRP). Technical direction for the overall study, of which the contract was a component, was provided by Dr. James J. Hester of the Department of Anthropology, University of Colorado, while on an Intergovernmental Personnel Act Assignment to WES. Dr. Hester also provided technical editorial review of the final workshop proceedings and wrote the Introduction. General supervision was provided by Dr. Raymond Montgomery, Chief, EED, and by Dr. John Harrison, Chief, EL. Dr. Roger Saucier, EL, was Program Manager, EIRP.

The workshop was organized and directed by Dr. C. C. Mathewson, and was held at the Aggieland Inn, College Station, TX, during the period 27-29 May 1987. Workshop participants were Dr. Hester; Dr. Richard Gould, Department of Anthropology, Brown University; Dr. David Carlson, Department of Anthropology, Texas A&M University; Dr. Donny L. Hamilton, Department of Anthropology, Texas A&M University; Dr. D. Gentry Steele, Department of Anthropology, Texas A&M University; Dr. Vaughn M. Bryant, Jr., Department of Anthropology, Texas A&M University; Dr. Michael R. Waters, Departments of Anthropology and Geography, Texas A&M University; Dr. Herbert Haas, Department of Geology, Southern Methodist University; Professor John F. Griffiths,

*Although "archeological" is the preferred spelling in government publications, "archaeological" has been used in this report when preferred by an author.

Department of Meteorology, Texas A&M University; Dr. Kenneth L. White, Department of Geography, Texas A&M University on IPA assignment with the Geotechnical Laboratory, WES; Dr. Wayne A. Dunlap, Department of Civil Engineering, Texas A&M University; Dr. Martha L. Scott, Department of Oceanography, Texas A&M University; Dr. C. Thomas Hallmark and Dr. Lawrence P. Wilding, Department of Soil and Crop Science, Texas A&M University; Dr. Mary K. Wicksten, Department of Biology, Texas A&M University; Dr. Ken Wilkins, Department of Biology, Baylor University, and Dr. William J. Clark, Department of Wildlife and Fisheries Science, Texas A&M University. The original manuscript was compiled, edited and prepared by Ms. Dee A. Dunton, Research Assistant, Center for Engineering Geosciences. The Interdisciplinary Bibliography of the Cultural, Physical, Chemical, and Biological Factors Affecting Archaeological Sites (Appendix A) was compiled by Ms. Tania Gonzalez, Graduate Research Assistant, Center for Engineering Geosciences. Ms. Julie Keaton, Ms. Janet Mathewson, and Mr. David R. White of the Center for Engineering Geosciences provided technical assistance.

COL Dwayne G. Lee, EN, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

This report should be cited as follows:

Mathewson, Christopher C. (editor). 1989. "Interdisciplinary Workshop on the Physical-Chemical-Biological Processes Affecting Archeological Sites," Contract Report EL-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters

INTERDISCIPLINARY WORKSHOP ON THE PHYSICAL-CHEMICAL-BIOLOGICAL PROCESSES AFFECTING ARCHAEOLOGICAL SITES

INTRODUCTION

James J. Hester
University of Colorado and
US Army Engineer Waterways Experiment Station

1. This workshop was funded by the US Army Corps of Engineers (CE) in support of its mission, mandated by Congress, to protect and preserve cultural resources present on the lands that it manages. The CE is involved in the management of these resources on over 1,000 projects situated on several million acres. As a result, research has been initiated to provide the CE with design and management guidelines, predictive models, and quantification of effects so that CE cultural resources personnel can select, justify, and use effective techniques to manage the cultural properties on CE lands. The present effort, termed "In-Situ Preservation of Cultural Sites," is part of the Environmental Impact Research Program (EIRP) based at the US Army Engineer Waterways Experiment Station, Vicksburg, MS, which is under the direct management of Dr. Roger T. Saucier. The research on In-Situ Preservation of Cultural Sites has been my responsibility for the past three years and therefore it seems appropriate to describe here the evolution in thought and practice leading up to this workshop.

2. Concern with cultural properties and their preservation began with the Antiquities Act of 1906, and that concern has continually been expanded and refined through a long series of subsequent acts and regulations. Most important among these are the Historic Preservation Act of 1966 as amended in 1980, the Reservoir Salvage Act of 1960, the Archeology and Historic Preservation Act of 1974, and the Archeological Resources Protection Act of 1979. Most significant among the regulations promulgated are those based on the National Historic Preservation Act (36 CFR Part 800), those implementing the Archeological Resources Protection Act (43 CFR 7, 36 CFR 296, 18 CFR 1312, and 32 CFR 229), and most importantly for the CE the recently adopted regulation ER 1130-2-438. A compilation of these laws and regulations is available in Schroedl (1987).

3. The concept of the preservation of cultural resources has evolved through time and is reflected in the language in those laws and regulations. In order to conserve space I shall refer to these concepts in the most abbreviated manner possible.

4. Initially, the concern as expressed in the 1906 Antiquities Act was with identifying and establishing specific sites of outstanding importance as National monuments and parks. Secondly, procedures were established to regulate the scientific study of such sites. With the passage of the Historic Preservation Act, the concept of a National Register of Historic Places was introduced. In that procedure, sites deemed "significant" were "nominated" to the Registry and as a result were given certain protection from impacts generated by Federal undertakings. This process, termed the Section 106 process, requires Federal agencies to identify and evaluate sites to be affected by Federal projects and to afford the Advisory Council on Historic Preservation an opportunity to comment. Under regulations adopted by the Advisory Council, sites to be affected by Federal undertakings could be avoided, preserved in place, or mitigated if they were to impacted by the project. The latter process, termed "No-Adverse Effect," stipulates that if the data present in the sites can be recorded and recovered, then the project may proceed. This procedure has become the favored option to the extent that data recovery through excavation of cultural sites had come to be synonymous with "mitigation," and preservation options have been given a lesser priority. Site avoidance, a second option, has also been widely practice but has rarely been evaluated in terms of its effectiveness after the completion of the project. When avoided sites have been revisited, they often show evidence of continuing impacts, though not necessarily project related.

5. In fact, the Historic Preservation Act and implementing regulations stress that "preservation" is the preferred option. This option, while rarely chosen in the past, has in recent years become more prominent. This concern for "in-situ preservation" led to the funding of the present research. This research includes a broad range of topics pertaining to methods and techniques suitable for in-situ preservation. Goals include developing techniques to reduce or eliminate detrimental impacts to sites, evaluating the effectiveness of those techniques be means of long-term monitoring, and transferring technology applicable to preservation from various scientific and engineering specialties to archeology. The information so acquired will be incorporated into CE planning and management guidelines and practices.

6. To date, research topics being studied or scheduled for study include:

a. The Nature of Site Impacts.

b. Site Burial Effects.

c. Structural Stabilization of Sites.

d. Soil and Rock Stabilization.

e. Stabilization by Means of Revegetation.

f. Camouflage and Diversionary Tactics.

g. Site surveillance.

h. Stabilization of Existing Structures.

i. Faunal and Floral Control.

j. The Use and Effectiveness of Signs.

k. The Effects of Inundation.

7. This workshop on the effects of site burial is thus part of a larger focus on research to identify techniques that are effective in the preservation of different site types situated in a wide range of environments and threatened by a variety of detrimental impacts. We need to identify the characteristics of site burial in order to know when it should be selected as the preferred preservation option in a specific case.

8. Prior efforts at site burial have assumed that burial is an effective method of preserving site contents from impacts. The purpose of this workshop is to further refine the understanding of the advantages and disadvantages of burial as a preservation technique. This aspect has legal ramifications as well; for example, if a site is buried, has it legally been protected and preserved? Presented in its simplest form, the question asked is: "If you bury a site, what happens? Does the groundwater table rise? Does the flow of groundwater increase? Are there changes in pH? Changes in compaction? Changes in habitat of flora and fauna? Will changes in topography increase or decrease erosion or modify soil formation processes? Finally, how do each of these changes affect specific site components such as bone, pottery, shell, and C-14-datable materials?" The papers present in this workshop provide a convenient and detailed summation of current scientific knowledge concerning these site burial phenomena and their influence on cultural materials, and will serve to guide the direction of future research.

References

Schroedl, Gerald F. 1987. "United States Government Documents Pertaining to Archaeological Resource Management," Department of Anthropology, University of Tennessee, Knoxville.

INTRODUCTION TO THE WORKSHOP AND THE CONCEPT OF A SITE DECAY MODEL

Christopher C. Mathewson
Center for Engineering Geosciences
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Introduction

1. The United States Army Corps of Engineers and other federal and state engineering organizations are faced with the responsibility of protecting the Nation's archaeological resources impacted by public projects. Numerous options are available to the engineer, ranging from a complete archaeological excavation to site protection through burial. In many cases, it is not desirable to excavate the site, since this effectively destroys the total archaeological resource by removing artifacts from their environment. The concept of site protection through burial maintains the total archaeological resource in place. However, little is known about the short and long-term impact of site burial on the archaeological record preserved in the site. The primary focus of this workshop will concentrate on the effects of site burial to develop a model to answer the question: "How will site burial as a preservation technique affect the site status?"

2. There are many human-caused factors which may impact sites, such as vandalism, land leveling, collecting, construction and land development, brush chaining, logging, and many others. Natural impacts include erosion, groundwater leaching, frost action, forest fire, subsidence, earthquake-induced surface processes, and numerous others. Our concern in this workshop is to ascertain how these processes, which are part of the overall site decay process, may be affected, either positively or negatively, by site burial. The question is, if we seek to protect a site by burying it, what effect will that have on the nature of the site contents? We will concentrate our inquiry to burial in a non-aqueous environment and expand on the results of the National Reservoir Inundation Study with respect to sites buried in an aqueous environment.

3. Archaeological sites are subject to multiple impacts resulting from both natural and human causal factors. The result is a cumulative degradation eventually resulting, if unchecked, in total site loss. Technological means are sought to retard or prevent such factors from impacting sites. However, prior to the implementation of prevention measures, we must assess the full range of site formational and decay processes to understand how sites come to be as they are and how they continue to exist. At the heart of this is the question "How does an archaeological site respond to changes in the physical,

chemical, and biological conditions at the site?" and "How, and at what rate, do changes in the site conditions cause changes in the archaeological materials?" Only with this kind of specific information for individual site components, such as soil, charcoal, bone, pottery, lithics, and other materials, can we assess the effects on the site of any protective efforts we may employ.

4. The kinds of changes we need to assess include: compaction; fracturing; movement of components, both horizontally and vertically; changes in chemical and isotopic fractions; sorting of components; remnant magnetism, thermoluminescence; component loss; and many others. A further consideration is the degree of change that we will accept as a result of our interaction with the site. Because sites have been in place for hundreds or even thousands of years, we often assume that the site exists as a relatively constant entity. Whereas the excavator may choose to view a site as a fixed entity at the time of excavation, in fact, a site is located along a continuum of change over time. Therefore, preservation cannot be defined as non-change, but instead should be defined as "any action which reduces or eliminates detrimental changes resulting from site impacts." The goal then is that preservation activities should reduce the rate of change of the ongoing natural processses on the site matrix and contents. This definition should also have legal implications:

a. The goal of preservation is not to prevent change, but to reduce or shield a site from adverse human and natural impacts.

b. Preservation involves what is technologically and financially feasible at present; i.e., "is it an achievable goal?"

c. Preservation is limited to the length of time that the technique utilized will afford protection.

5. Further, since our approach is an applied effort, we wish to develop technologies of site protection through burial that will have predictable impacts. Our concerns are not theoretical nor are we interested in the full range of archaeological method and theory. We are seeking to develop a site decay model that is able to predict and anticipate the effects of different forms of site burial on the characteristics of the total archaeological resource.

Concept of a Site Decay Model

6. The ultimate objective, of which this workshop is a beginning, is to develop an archaeological site decay model that can be applied to the preservation of a site. The general concept of the model envisioned can be patterned after a model of forest

succession, except that the forest is renewable and an archaeological site is not. The plant community that develops and changes through time is responding to numerous external factors, such as climatic patterns, insects, soil conditions, slope, fire, and others. Each of these factors may act to either enhance or retard the rate of forest development in any number of ways. For example: climate is seasonal; bedrock is effectively constant; fire is a negative step function; and soil characteristics are gradual.

7. Schematic diagrams of the process-time relationship for forest succession and archaeological site decay are shown in Figure 1. In the case of Figure 1A, the independent variables controlling the rate of forest development are uniform throughout time and a smooth succession curve is generated. Once the forest system reaches climax and is in equilibrium with the independent variables, a change in these variables must occur before forest conditions change. In Figure 1A, this is shown by the introduction of a new variable (fire) which causes a negative step function drop to bare mineral soil conditions. In the case of an archaeological site, Figure 1D shows a uniform decay rate for a specific component of the site. If the independent variables are cyclic, they could produce the forest development-time relationship in Figure 1B, or prevent the forest from ever reaching equilibrium, as in Figure 1C. External impacts on an archaeological site can either increase the rate of decay (Figure 1E) or retard the rate, as in Figure 1F.

8. Each independent factor can be investigated within the related field of specialty; however, in this workshop, we propose to draw together each of the specialists so that the interactions between each of the independent factors can be combined to develop a single model. In this manner, we hope to be able to identify the influence of one variable on another as it affects the decay of an archaeological site. Our initial approach will be to treat each component of an archaeological site as a unique dependent variable, rather than attempt to treat the site as a whole. Ultimately, it would be desirable to treat the site as a whole; however, we believe that the necessary data and understanding of the process-time relationships does not exist at this time.

9. The general decay-time relationship is expected to take the form of a "factorial equation," similar to the one below:

$$SD = f(Aa^{\alpha} + Bb^{\beta} + Cc^{\gamma}) + g(Dd^{\delta} + Ee^{\varepsilon} + Hh^{\mu}) + \ldots\ldots\ldots$$

in which, SD = site decay rate; f and g are interaction functions; A, B, C, D, ... are constants; a, b, c, d, ... are independent variables derived from each of the interacting sciences; and α, β, γ, ... are exponents established by the time relationship of each independent variable. As this proposed equation suggests, attempting to develop a

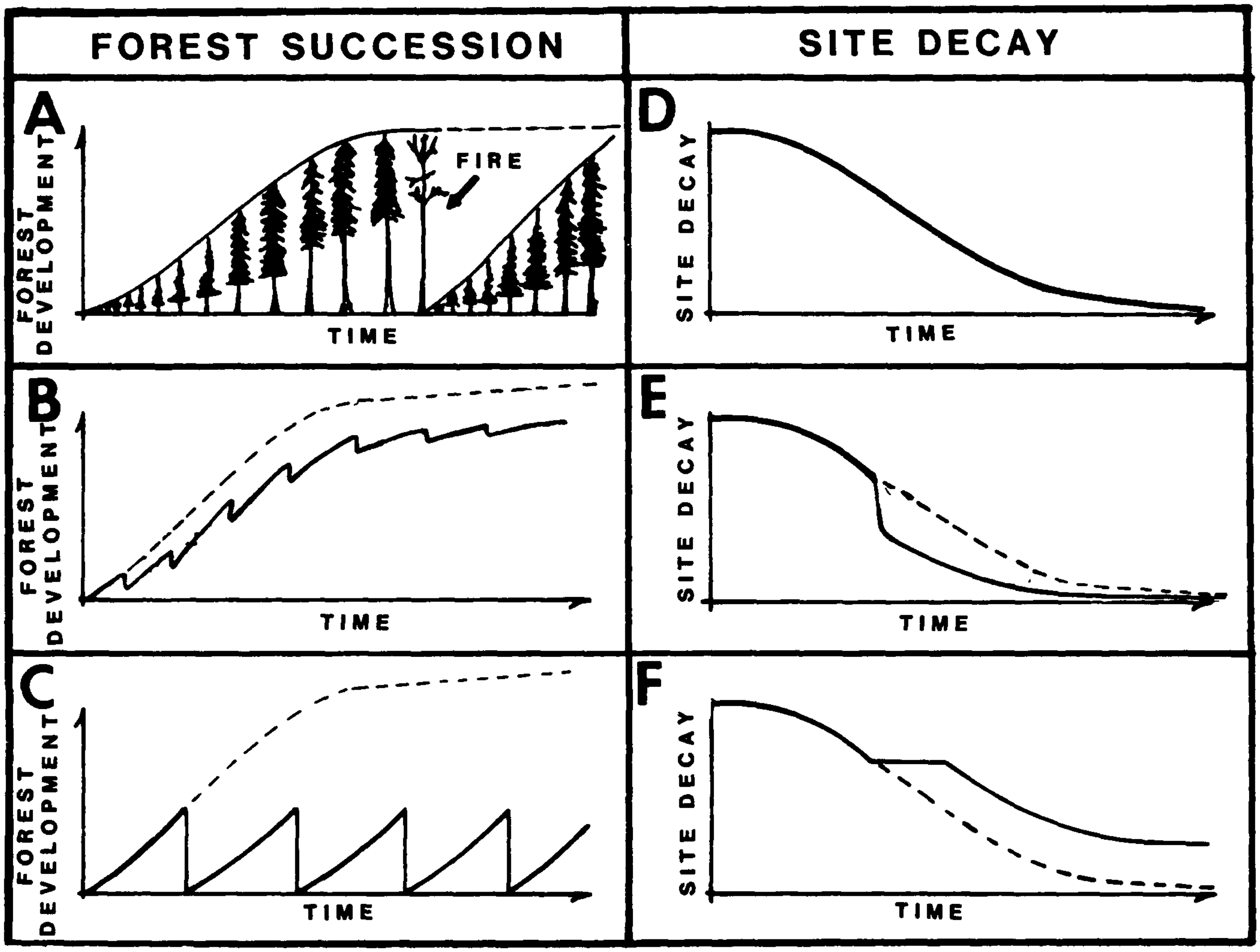

Figure 1. Schematic process-time relationships for forest succession and archaeological site decay. In (A) and (D), the independent variables are uniform and the process-time relationship follows a smooth curve. A significant external, independent variable, fire in (A) causes an abrupt step function change in the process-time relationship. Non-uniform or cyclic changes in the value of the independent variables cause irregular process-time relationships. The influence of changes that increase decay (E) or that retard decay (F) are the primary objective of this workshop.

quantitative archaeological site decay model is an ambitious and challenging project beyond the scope of this workshop.

10. Critical to the ultimate development of a quantitative site decay model is the identification of the interactions of the physical, biological and chemical factors with the components that make up an archaeological site. This workshop will concentrate on the identification of these factors and their relative or expected effects on the decay of specific artifacts or site features. This workshop will attempt to construct a site decay matrix that relates the effect of a post-formation change in the physical, biological and chemical processes to the decay or preservation of specified archaeological site components. The matrix will provide a needed component in the planning, evaluation and design for the protection of archaeological sites.

ARCHAEOLOGICAL FRAMEWORKS FOR EVALUATING SITE-FORMATION PROCESSES

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1. Site-definition and an understanding of site-formation processes have proved to be among the most intractable problems in archaeological method and theory. Textbook definitions abound, but these are mainly descriptive in nature and fail to offer sufficient controls for analytical archaeology. Perhaps the most widely cited and used of these definitions is the one proposed in 1958 by Willey and Phillips:

> A site is the smallest unit of space dealt with by the archaeologist and the most difficult to define. Its physical limits, which may vary from a few square yards to as many square miles, are often impossible to fix. About the only requirement ordinarily demanded of the site is that it be fairly continuously covered by remains of former occupation, and the general idea is that these pertain to a single unit of settlement, which may be anything from a small camp to a large city. Upon excavation, of course, it rarely turns out to be that simple. The site is the basic unit for stratigraphic studies; it is an almost certain assumption that cultural changes here can only be the result of the passage of time. It is in effect the minimum operational unit of geographical space.

How quaint this discussion of the site seems now with the benefit of almost 30 years of hindsight! Yet the problems inherent in descriptive definitions of this kind continue to affect archaeology, both in relation to research and to the requirements for effective cultural resource management.

2. The overriding problem has to do with controls. How can we achieve a controlled approach to the study and preservation of archaeological sites that will ensure scientifically acceptable results and workable management practices? The basic difficulty with descriptive definitions like the one cited above lies in the ambiguity of the meaning of the word, occupation. In common parlance, this word has two quite different meanings. One has to do with activities, such as a skill, trade or economic pursuit. The other relates to a physical space where people reside or perform various activities. Many archaeologists fail to disaggregate these two, alternative meanings of the term, occupation, although they constantly employ the term. This is a problem with the Willey and Phillips definitions, and it persists in textbooks, management documents, and even in technical archaeological site reports as well.

3. In order to achieve a controlled framework for evaluating archaeological results, we must first distinguish between the residential and activity-related components of our view of the site. This can only be achieved by considering the nature of archaeological sites and their formation from several different points of view. Each point of view presents a different concept of the site, and the choice of which concept to use will, ultimately, rest with the researcher or manager according to his/her goals. This paper represents a "first cut" at trying to sort out these different concepts of the archaeological site and to provide perspectives on site-formation processes that will be relevant to different research and management needs.

The Geographical Framework

4. The geographical perspective is, essentially, an empirical concept of sites as clusters of artifacts and features occurring together within a spatial context. Archaeologists characteristically "discover" such sites when they observe unusual concentrations of pottery, stone artifacts and debitage, hearths, architectural remains, and other visible markers indicating the presence of past human activity. Although this has been and continues to be a common way for field archaeologists to operate, the approach has seen much development and refinement away from such an arbitrary kind of method. In the course of developing archaeological methods for regional surveys, the focus has shifted steadily away from the individual site to the region and the relationship between particular sites to their regional context.

5. The most extreme example of this trend would be the so-called "siteless survey," advocated by Dunnell and Dancey (1983). Such an approach challenges conventional wisdom concerning the primacy of nucleated or localized sites in understanding past human behavior, and it disputes the assumption that site excavation is the primary means of acquiring useful information about past human behavior. The concept of the siteless survey views the material by-products of past cultural systems as potentially distributed across landscapes in time and space, with varying amounts of clustering. This approach seeks to establish data collection strategies that will provide controlled sampling over entire regions with measures of this clustering effect. For these researchers, surface surveys based upon controlled sampling strategies are more useful as a tool of discovery than the arbitrary designation (and excavation) of certain clusters of artifacts and features as sites. Or, in other words, the areas between sites are as important as the so-called sites, and it is just as important to control these areas "in between" as it is to identify and investigate the sites themselves. As they put it:

> With few exceptions, the notion of site continues to structure archaeological fieldwork. Archaeologists apparently believe that the record comes in finite bounded packages - remains that fall between those packages are irrelevant to the definition of the packages themselves...(Dunnell and Dancey 1983)

Serious consideration of this approach points out the circularity of reasoning inherent in conventional definitions of the site in archaeology, with such site definitions (such as the one cited earlier by Willey and Phillips) as particularly egregious examples of what philosophers of science refer to as the "Fallacy of Affirming the Consequent." That is, the site, as a construct in the mind of the archaeologist, cannot reliably be "discovered" in or on the ground and is therefore a poor approximation of the behavioral realities that actually structure the archaeological record as it occurs over the landscape. Such conventional definitions are a kind of <u>ex-post</u> <u>facto</u> discovery of something the archaeologist already expected to find.

6. With this critique in mind, we can begin to appreciate the recent trend in archaeology to develop better controlled methods of regional survey. Essentially, there are two kinds of survey approach possible within archaeology, and each one operates within its own distinctive domain. Nance (1983) calls these Discovery Model Sampling (DM) and Statistical Precision Sampling (SPM). Discovery model sampling involves establishing the degree of sampling intensity or effort required to detect cultural remains within a sampling domain. This form of survey entails an estimate of probability of discovering the particular kinds of cultural remains being sought within the total survey area. The likelihood that cultural remains of interest will be detected within a sampling domain using a specified sampling procedure will depend upon controlling for variables such as the visibility of cultural remains and the ability of the survey observers or sensing techniques to see these items. The key to using this approach is to establish a "target" indicative of past human presence and activity to ensure a probability of discovery of all such items occurring within the sampling domain. Nance (1983) indicates that, "...any such concept [of discovery probability] must be general enough to cope with all kinds of cultural remains and not just the high-density clusters that we refer to as <u>sites</u>." This approach works best in situations where it is practical and cost-effective to survey the entire area or region in question, for example, by means of an aircraft (in the case of land archaeology) or by remote sensing (in the case of underwater archaeology or the use of satellites) and where one has established beforehand that the cultural remains or "targets" can be observed under the prevailing conditions under which the survey is conducted. The result of such a survey appears in the form of a probability of discovery that all of the designated "targets" in the total survey area

were found - and, conversely, if none were found, that the same probability applies to the conclusion that these "targets" did not occur there.

7. Statistical precision sampling presents an alternative and quite different survey strategy. In this case the archaeologist is attempting to infer something about the quantitative properties of a large entity (a population) from the study of only a portion (sample) of that entity (Nance 1983). Such sampling may be based upon a simple percentage of the total survey area, or it can be established in the context of a stratified sample - related, perhaps, to local differences in terrain or vegetation within the total survey area. One difficulty with this approach is that it assumes some degree of homogeneity of cultural remains within the total survey area, which raises the problem of controlling the representativeness of the sample, a problem dealt with in detail by Read (1986). This is by far the most widely used survey strategy in archaeology today, especially in land archaeology where practical constraints of time, effort and resources make it difficult or impossible to cover the total survey area.

The Stratigraphic Framework

8. Dunnell and Dancey's comments notwithstanding, stratigraphic excavation continues to be the primary means available to archaeologists for making chronological and behavioral inferences about past human societies. Such excavations are, necessarily, focused upon those relatively nucleated or concentrated manifestations of past human activity we conventionally term "sites." However, archaeologists today are more sensitive to the regional and ecological context within which these sites occur and are less likely to treat single sites as somehow typical of whole cultures. Even within sites, it is apparent that stratigraphic excavations can occur within only a small portion of the total site area, in most cases due to practical considerations of time and cost. This means that archaeologists increasingly treat their excavations as a method of sampling within the area and total volume of the site, along the lines of Nance's statistical precision sampling model. This being the case, it has also become fairly standard archaeological practice now to leave a statistically significant portion of each site unexcavated, to serve as a potential "witness" for later testing of the homogeneity of the internal composition of the site that was assumed as part of the research design that guided the original excavations. It may seem ironic or even contradictory to some, but one of the most important controls in contemporary archaeological excavation has to do with ensuring how much of the site will not be excavated. This has important implications for managers who are concerned with long-term site preservation and conservation.

9. If site preservation is deemed to be important in any particular case, it will be essential to determine the degree of internal variability within the site, especially regarding the nature of the materials that constitute the fill and internal contents of the site. Different parts of the site may require different preservation strategies according to the nature of these internal contents, with, for example, a shell deposit requiring different conservation approaches from an area containing artifacts made of organic materials such as wood or fibrous materials. Thus coring or some other form of limited subsurface excavation will almost certainly be required in this sampling mode within a nucleated site before acceptable preservation decisions can be made. One must be able to anticipate the likely costs and benefits that would arise from a management decision at a site in relation to this problem of internal differentiation. One of the most important findings of this workshop has to do with the differential effects of different alterations to a site in any effort to preserve it, and these effects can only be evaluated if the degree of homogeneity at the site is known and can be controlled for within reasonable limits.

10. Considerable debate within archaeology has focused on the issue of how much or to what degree the patterning of material remains found associated at an excavated site reflects the activities of the people who produced them, as opposed to the effects of depositional or post-depositional factors of natural origin. Schiffer (1976) has proposed a useful distinction between the effects of these different processes. While all archaeologists are initially concerned with pattern-recognition involving material remains at archaeological sites, the interaction between natural and cultural processes to account for such patterning is complex and requires an organized and controlled approach. Schiffer contrasts N-transforms (processes of nature that operate to structure the archaeological record) and C-transforms (patterning due to the effects of human cultural activities). Muckelroy's (1978) discussion of the evolution of a shipwreck and the relationship between "filters" (elements which operate to extract materials from the assemblage) and "scrambling devices" (which rearrange the patterns of these associated materials) applies similar reasoning to the problem of evaluating underwater sites, although the cultural and natural processes he refers to cross-cut the distinction between filters and scramblers.

11. Almost every archaeological site report that has ever been written or published can be criticized at some point for ambiguities arising from some failure to control for the relative effects of cultural and natural factors in structuring the excavated assemblages. Archaeological theorists can, in a rough and ready way, be distinguished between those like Binford (1981) who emphasize the importance of material assemblages as evidence of fossilized human behavior in the archaeological record and those who argue (like Schiffer) for the need to control for natural factors before such cultural inferences can be drawn.

One of the most effective examples of an organized approach to this problem appears in the field of taphonomy, an approach developed by paleontologists to control for the effects of natural factors such as decomposition, scavenging, erosion, wind abrasion and weathering on death assemblages - that is, the association and condition of bones of animals after death. In the case of archaeology, this approach has been extended to include the effects of human activities on bone assemblages as well (Gifford 1975), and so far most efforts in this area have focused on faunal remains having to do with early hominids in East and South Africa (Brain 1981). Taphonomic studies have been carried out in a variety of contexts ranging from ethological studies of scavengers and the differential effects of their activities on carcasses in the wild to the laboratory experiments such as flume studies to measure the differential effects of varying water velocities on the transport of bones of different shape, size and weight. The general approach represented by taphonomy is clearly applicable to every domain of archaeology where there is a need to distinguish between and control for the relative effects of the behavior of the human species and the behavior of nature.

12. In applying such controls, it may be useful here to identify two basic kinds of site abandonment tha have long been appreciated (though not always recognized as such) as dominating the physical record of the human past. One of these, instantaneous abandonment, occurs when an entire human community or locus of human activity is entombed as a result of purposeful burial or some cataclysmic event in nature. Situations of this kind are relatively uncommon on land, but when discovered, these occurrences tend to attract considerable public attention. Pompeii and King Tut's Tomb are perhaps the best known examples of this phenomenon, and part of their fame rests upon their relative rarity in the archaeological record. But less spectacular examples of such occurrences can be found in many land sites, especially in the form of gravelots and burial associations. Such occurrences are common under water, in the form of shipwrecks and submerged terrestrial sites. A good example of the former would be the much-publicized location, sonar-imaging and photography of the wreck of the R.M.S Titanic, while a good example of the latter would be the archaeological recording of the submerged harbor in Port Royal, Jamaica (Hamilton 1984).

13. A more common and prosaic kind of formation process on terrestrial sites relates to the gradual alteration of human habitation sites or activity areas. Such progressive abandonment presents the archaeologist with more complex physical associations that result from changes arising from modifications to the site due to disturbance, displacement and reuse of materials and objects. Sometimes, both instantaneous and progressive abandonment can occur within the same site-locus, thus

requiring the archaeologist not only to recognize and distinguish between them but also to account for them by means of different modes of explanation. Such cases may arise on land, in sites where long-term human residence was punctuated by burials, shrines, or other loci indicative of instantaneous or very short term occurrence. For example, the well known site of Tell es-Sultan (Jericho) contains evidence of intensive human habitation from almost 10,000 years ago involving, among other things, the progressive construction, modification, destruction, reuse and reconstruction of numerous masonry and mud-brick walls that have been debated by several generations of archaeologists (Garstang and Garstang 1948; Kenyon 1957) while also containing tombs from the Bronze Age that represent archaeological associations produced by a very short interval between their creation and abandonment. While natural processes can be identified to help account for these occurrences (such as the preservation of wooden grave furniture in the Bronze Age tombs of Jericho due to seepage of anaerobic gases into the tombs from fissures in the rock into which the tombs had been cut or earthquakes in certain cases where walls have collapsed) cultural explanations cannot be achieved by means of archaeological criteria alone. The same is true for underwater sites, such as the unusual case reported off the east coast of Florida near Fort Pierce (Cockrell and Murphy 1978), where Pleistocene-age remains of Paleo-Indian activity were discovered directly underneath the wreck of an 18th Century Spanish ship. As in the case of Jericho, each of these site components will require a different kind of theory to account for the remains, and for each category of remains there must be controls to allow for the appropriate use of natural and cultural explanations. The natural and physical sciences, as demonstrated by stratigraphic archaeology, taphonomy, and sampling methods, provide one body of appropriate theory based on uniformitarian assumptions, but what about appropriate theory based upon human cultural behavior, where it is difficult and even impossible to make scientifically acceptable uniformitarian assumptions?

14. To illustrate the importance of cultural factors in accounting for material remains associated with different kinds of abandonment behavior, a recent study of historic mining camps in the southwestern Yukon of Canada (Stevenson 1982) should be noted. Following up on hypotheses proposed earlier by Schiffer, the materials associated at these different mining camps were systematically compared to see to what extent they conformed to expectations provided by historic documents. The documents afforded indications as to whether or not the miners intended to return to these camps, and it was thus possible to test archaeologically for situations that reflected abandonment with no intentions of returning to the site as opposed to situations in which the miners intended to return but were prevented by circumstances from doing so. Each situation produced measurably

different material assemblages. Cases like this indicate the need for us to consider more explicitly cultural frameworks for evaluating site-formation processes.

The Ethnographic Framework

15. Having controlled for natural site-formation processes, what about cultural factors? Here we must look to the ethnographic record for relevant approaches to understanding the behavioral realities of the archaeological record. The most potent source of ideas on this subject is the subdiscipline of ethnoarchaeology. In its most general sense, this approach consists of ethnographic studies of contemporary human societies from an explicitly archaeological point of view - that is, with the aim of identifying and explaining the operation of cultural processes that structure archaeological patterning in particular cases. However, ethnoarcheologists differ in their ways of doing this according to differing research agendas. Each approach must be evaluated in terms of its own goal and its relevance to the sites and site-assemblages the archaeologist wants to explain.

16. Perhaps the most common form of this approach is what I shall call "dirt" ethnoarchaeology. The primary goal in this case is to find a direct historical connection between the contemporary or historical societies in a particular region and the archaeological sites and material assemblages of that same region. This approach has been widely applied in places like the American Southwest and Great Basin, where it has been termed the "direct historical approach" by North American archaeologists (Heizer 1941; Steward 1942). In each of these regions archaeologists have developed detailed strato-chronological sequences from the terminal Pleistocene to the historic present, in the former case culminating in the modern Pueblos and their Athapaskan-speaking neighbors (Navaho, Apache) and in the latter case in the Paiute and Shoshone hunter-gatherers. In each case, what has impressed archaeologists the most has been the stratigraphic and historical continuity between the prehistoric and historic manifestations of these cultural traditions. For example, the "Desert Culture" concept (more recently termed "Desert Archaic") of the Great Basin of North America represents the idea that relatively small groups of mobile hunter-gatherers pursued a regular seasonal round of foraging activities within different, altitudinally stratified resource procurement zones throughout the Great Basin region. Each group foraged within its own intermontane basin (such as the Reese River Valley, Owens Valley, Pyramid Lake region, Wendover Basin, etc.), and local variations in group size and composition, technology, and residential patterning are seen in relation to local differences in the biogeographical conditions. This ethnographic model originated from studies by Steward (1938) of historic and ethnographic Great Basin Indians

and was quickly adopted by archaeologists such as Jennings (1957) during his work at Danger Cave in Utah and more recently by Thomas (1973) and O'Connell (1975) in other subareas of the Great Basin.

17. Another, even older variant of this approach has to do with establishing the historicity of oral traditions. Schliemann's search for Homeric Troy and the efforts of Biblical archaeologists in Palestine indicate how much of the energy of early archaeology in the Near East was directed by this interest. Attempts to link oral-traditional and biblical accounts to the archaeological record have been a persistent theme in this part of the world, as, for example, in the case of the 10th Century B.C. copper refineries discovered by Gleuck at Ezion-geber, on the Gulf of Aqaba in 1938, and attributed to the reign of Solomon (Albright 1960) - the original "King Solomon's Mines." These efforts in the Near East can be matched with parallel cases from the American Southwest and Polynesia. But there is a persistent problem with these efforts to connect the archaeological past with the historic present. If one accepts the connection between a particular present-day culture or oral tradition and the archaeological remains of a past culture or civilization, could one ever know more about the past than the traditions or the modern example could tell? Instead of providing real tests, most of the early efforts in this direction merely sought confirmation of the traditions already known for the present-day cases.

18. "Dirt" ethnoarchaeology emerges as an excavation-directed form of ethnoarchaeology, in which the questions asked by the ethnoarchaeologist are controlled by the specific characteristics of those materials that have survived within the particular culture-historical sequence in the region being studied. This approach relies heavily upon the use of analogy for its application to the archaeological record, and disagreements and debates occur within the domain of "dirt" ethnoarchaeologists over which criteria positively identify the best analogues. One variant of this approach involves extending the ethnographic analogue discovered in one area to another region where there appears to be similar environmental conditions and where one is encouraged to assume that different cultures manipulated similar environments in similar ways (Ascher 1961; White and Peterson 1969). The greatest difficulties for this approach arise in situations where there is no modern or historic counterpart to the situation found occurring archaeologically, as, for example, in the case of pedestrian big-game hunting adaptations of the sort that prevailed in both the Old and New World during the terminal Pleistocene. "Dirt" ethnoarchaeologists characteristically find it hard to explain such historical discontinuities in the archaeological record, especially when the differences between the past and present in their particular region outweigh the similarities. Despite the preference archaeologists have shown for using this approach in their interpretations, "dirt" ethnoarchaeology is fraught with pitfalls

based on circular reasoning and must be subjected to a "testing mode" of analysis before it can be used effectively. That is, predictive models drawn from existing or historic ethnographic cases can be compared with archaeological patterning to see to what extent they correspond, with the understanding that a lack of correspondence will require an explanation other than the one provided by the present-day case. The use of this approach, however, still begs the question: How can other, alternative explanations of prehistoric or otherwise extinct cultural systems be developed in a scientifically acceptable manner?

19. In the historical sciences generally - that is, geology, paleontology, and astronomy - the principle of uniformitarianism serves as a bridge between the past and present. The assumption that processes observed in the present operated uniformly and in the same manner in the past allows us to make generalizable inferences about what it was that structured the archaeological record. The key here for archaeologists is to know when such assumptions are acceptable. There is no such thing as "cultural uniformitarianism," meaning that we cannot safely assume a priori that different cultures will behave in similar ways under similar circumstances, since each cultural system operates under its own set of learned behaviors and shared categories of experience. Such learning is structured largely by the rules established within the particular cultural tradition (such as the "rules" of grammar in a language) rather than by uniformitarianism laws that apply in all cases and at all times.

20. The challenge of ethnoarchaeology today is to develop general, law-like principles of human behavior that conform to acceptable uniformitarian expectations while, at the same time, distinguishing and explaining those aspects of the archaeological record that are structured by the grammar-like "laws" of a particular culture-historical tradition. This is possible only within the context of a set of scientific controls of the sort described earlier in this paper, combined with an awareness of contemporary ethnography, especially in relation to material behavior and the characteristic residues of that behavior. In the natural and physical sciences generally, the acceptability of a law or general principle depends upon its ability to account logically and parsimoniously for particular cases, and this is no less true for the social sciences. But, unlike the natural and physical sciences, we must also be prepared to control for the learned, cultural component of that behavior in each particular case. Lack of such control can produce results that leave archaeologists open to the accusation of scientific softness or even pure invention in their attempts to explain the past.

21. A brief example from the Western Desert Aborigines of Australia illustrates the value of controlled ethnoarchaeological approaches to the study of cultural factors affecting site formation processes. Aboriginal sites studied in 1966-70 by the author varied

considerably in size and function, ranging from maximal aggregations of population of up to 107 people (both sexes, all ages) from approximately 2-3 weeks under conditions of localized rainfall and abundance of game to minimal groupings of as few as six people (again, both sexes, all ages) camping together under conditions of prolonged drought, usually at or near a water-source that served as a drought refuge. Depending upon the rainfall and surface water catchments at the particular time and place, these aggregations would disperse and re-form in a flexible, opportunistic manner along this spectrum. When looked at ethnoarchaeologically, these habitation sites presented the widest detectable range of activities, as evidenced by the material residues of those activities. These activities including stone tool-use and manufacture, butchering and consumption of meat, seed-grinding and other plant food preparation, manufacture of wooden artifacts and objects of fibrous materials (like bark sandals) preparation of body decoration (mainly in the form of red ochre), and sleeping areas (distinguishable by a particular pattern of hearths and cleared spaces on the ground. (See Figure 1.)

22. There were also several kinds of task-specific sites in which a limited number and variety of personnel (usually one sex, and a restricted age range) performed a single or limited task. Many such sites were related to resource procurement and included such loci as lithic quarries, trees from which wooden preforms for various implements were removed, and bedrock seed-grinders, but there were several kinds of specialized ritual and ceremonial sites as well that should be included in this category. (See Figures 2-4.)

23. Systematic comparison of the material residues at these different kind of sites revealed a greater congruence and higher degree of archaeological visibility of material remains vis-a-vis specific activities at task-specific sites than was true for most residential habitation sites. This was despite the fact that residential habitation sites were always larger and contained more materials than task-specific sites. This apparently counterintuitive result was due to the effects of a C-transform I have elsewhere referred to as the "principle of interference," (Gould 1980) which states that the longer a group of people resides at a particular site, the more interference occurs with the associated remains of previous activities. Duration of habitation can be measured in person-days, meaning that it can arise from a small group camped in one place for a long time or from a large group settled in one place for a shorter time. One result of this process of interference is a tendency toward disassociation of activity area-related artifacts, features, and other site residues. Different activity-area residues become disassociated at different rates, with object size and shape emerging as important factors along with the potential for reuse or recycling of certain kinds of artifacts and/or raw materials. In general, large and bulky objects like stone seed-grinding slabs (which often weigh over 20 kg) and very small items

Figure 1. Residential campsite at Wanampi Well, Dec. 13, 1966. This Western Desert Aborigine site contains the largest number of people (107) for 2-3 weeks.

Figure 2. Task specific site: An emu roasting pit.

Figure 3. Task specific site: A Western Desert Aborigine man splitting off a slab of acacia wood to fashion into a spearthrower, N. of Warburton Ranges, W.A.

Figure 4. Task specific site: A seed grinding locality. Aborigine woman preparing to grind wangunu seeds.

like stone flakes less than about 5 cm in diameter move less than items of intermediate size and weight. Scuffing, due to the constant motion of people and dogs across the habitation site, is a dominant factor accounting for the progressive blurring of activity areas within habitation sites, but sweeping activities, no matter how impromptu in nature, also account for much of this.

24. Task-specific sites, while generally small and short-term, showed clearer and more durable associations between material residues and more accurately reflected the behavior that produced them. There was little or none of the scuffing, sweeping, reuse, or recycling found at residential, habitation sites to disturb the association after it had formed. Thus, task-specific sites possessed greater potential archaeological visibility with regard to the relationship between particular kinds of material residues and human behavior than was true for residential habitation sites. This brief example reveals some of the behavioral realities that structure the archaeological record, especially when it comes to evaluating the archaeological potential of residential vs. task-specific sites. An archaeologist who surveys or excavates a residential site will have to evaluate the material associations represented at the site differently from the associations at a task-specific site. That is, the degree of task-specificity at the site will need to be examined first before the nature of the physical associations represented there can be appreciated or controlled for. Among other things, this small example should serve as a caution to any archaeologist who fails to distinguish between the residential and task-related aspects of the term occupation when considering archaeological site-formation processes.

25. Recognition of this kind of ethnographic patterning has direct management implications for site preservation which will seem counter-intuitive to many archaeologists. From ethnographic cases such as the one just described from the Western Desert of Australia and many others we can conclude that relatively task-specific sites will have the following attributes: 1. They will be small and ephemeral, with a limited range and amount of material remains to reflect their presence. Some exceptions to this generalization occur in the form of sites like lithic quarries subjected to repeated revisits and reuse, but even in such cases the range of different artifact and debris patterns is limited even when the amount of material is not. 2. They will be distributed over the landscape in areas that are often remote from nucleated habitation sites (the areas "in between" sites referred to by Dunnell and Dancey 1983). 3. They afford the best opportunity for making direct inferences about the human activities that produced them. Ethnoarchaeological findings compel us to recognize the potential importance of these sites for understanding different task-oriented aspects of ancient human behavior, in contrast to the difficulties posed by relatively nucleated habitation sites where it is difficult

to build controlled inferences of this kind. Thus, from a management point of view, it may be more important to excavate these smaller, more task-specific kinds of sites in an area threatened by major development and to focus on preservation for the larger and more nucleated habitation sites. Most archaeologists still tend to focus their efforts on relatively large, nucleated sites that served as habitation areas and would assign these a higher priority for excavation than the smaller, more ephemeral sites in the area. However, it may never be practical to preserve such task-specific sites, and ethnoarchaeological findings support management strategies that would excavate these first and preserve the more nucleated sites for later study.

26. There is a strong move now among ethnoarchaeologists to develop explanations of past human behavior based upon controlled approaches that allow us to distinguish the relative effects of these general and particularistic factors upon the archaeological record. For example, recent studies in contemporary hunter-gatherer ecology among groups like the !Kung San (Bushmen) of the Kalahari Desert and the Western Desert Aborigines of Australia have led to studies that explain the patterning of campsites, especially the distance between individual camps and the population density of these camps - in relation to ecological variables such as relative predation pressure (Gould and Yellen 1987). Similar efforts are underway to account for patterning of material residues in more complex, modern societies, as in recent ethnoarchaeological studies of urban gardening in the Boston area (Mrozowski 1987), the effects of changes in transport technology on historic and present-day Saami (Lapp) reindeer herders in northern Sweden (Wheelersburg 1987), and processes of farm abandonment in northeastern Finland (Gould in press). If the same level of controls are consistently applied in these kinds of residue-oriented studies of contemporary human behavior, then ethnoarchaeology will provide a convincing framework for explanations of the cultural component of site formation processes in the archaeological record.

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ARCHAEOLOGICAL TECHNIQUES, METHODS AND SAMPLING

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Introduction

1. Conveying an appreciation of archaeological methods and techniques in a few pages is a difficult task. Part of the difficulty stems from a general lack of understanding regarding the goals of archaeology. Most people know that films like "The Mummy" and "Raiders of the Lost Ark" do not provide an accurate portrayal of archaeology and archaeologists. Fewer people are aware that the photogenic sites which fill the pages of National Geographic are the exceptions rather than the rule. The purpose of this paper is to explain to non-archaeologists what it is that archaeologists do.

2. Most misconceptions concerning archaeology are not so much inaccurate as they are incomplete. The public recognizes that archaeologists are interested in old things and ancient civilizations and lost works of art. They are less aware that archaeologists are also interested in stone flakes, animal bones, and pollen. Other misconceptions of archaeology stem from the belief that each archaeological site stands alone, that the archaeologist spends a lifetime trying to understand a single site. While this may be true for a few archaeologists, many of the questions we try to answer cannot be answered at a single site. To address complex questions such as the development of agriculture, archaeologists need more than one site, more than one example of a time period and region. Just as the political pollster would hesitate to come to a major conclusion on the basis of a single interview, the archaeologist must use information from a variety of excavations in order to understand past events.

3. Archaeology is not an experimental science in any traditional sense. If anything, it is the opposite of an experiment. The experiments have already taken place; the archaeologists' task is to find out what they were and what implications they have for understanding our humanity. It is a little like entering a chemistry lab after the students have left and trying to figure out what experiments they were running from the broken test tubes and the arrangement of things in the room. The history of archaeology is one of steady improvement in the quality of our techniques and in our ability to figure out what the experiments were. At the same time, we are still learning. For this reason it is not always possible to say that a particular aspect of a site is irrelevant to understanding the

past or that a particular artifact is expendable. Nevertheless, archaeologists working in cultural resources management make these decisions every day. In fact, every archaeologist who is excavating a site makes these decisions, although not all of them are completely aware of it.

4. Since the methods and techniques of archaeology make little sense without an understanding of the goals of archaeology, it is appropriate to begin a discussion of archaeological method and theory with a summary of the goals of archaeologists.

Goals

5. Archaeologists have a variety of goals. In general they can be classified into three groups, depending on whether their major emphasis is on artifacts, on sites in a region, or on changes through time (see for example Binford 1968; Fagan 1985). This grouping also provides us with a rough scale from simple to complex. Simple goals are addressable by digging part of a single site. The more complex ones involve substantial excavations at many sites.

Artifacts - recovering evidence of past craftsmanship

6. The first archaeological excavations were conducted in order to recover art objects for display in museums. While this is rarely a major goal of modern archaeology, it is often a subsidiary one, particularly if it can be tied into finding the earliest example of a particular artifact type or style. Not much different is the goal of finding a site which contains the first evidence of some practice (e.g., the earliest agricultural village). This goal is confined largely to sites which were occupied by complex societies or civilizations where artifacts were made by specialized craftsmen, or to sites which are very old (see for example Daniel 1967 and Wilby and Sabloff 1980).

7. A related goal involves organizing artifact styles for a given region into a chronological sequence. Often this is done by comparing artifacts from a single stratified site which contains artifacts from several different periods. This makes it possible to provide at least a relative date for an object. Using the date of the artifact to date the site, it is possible to group sites which were occupied during the same period. When the sequence for a particular region has been worked out in some detail, it is possible to estimate the age of artifacts which were not recovered from controlled excavations. This study of artifact styles and the way they change through time and space is called culture history.

Sites - inferring how people lived

8. While the study of particular artifact styles makes modest demands on the quality of archaeological data, studying how people lived requires more detail. Often the focus is on a particular occupational zone in a particular site, but other contemporaneous sites in the area are often used as well. Studying how people lived requires that a wide variety of materials be recovered from the site. Broken pottery, animal bones, carbonized nutshells, stone flakes and other materials can all provide information on how the artifacts were made and used. The distribution of materials on the site and the locations of houses and other features provides information about the settlement plan. The location of the site itself tells us about the criteria used to select particular locations for settlement. The bones and carbonized plant remains provide evidence of what people were eating and possibly what time of year they were there. The bones of the inhabitants themselves can tell us about their general health and life expectancy.

9. By combining the data from all of these studies, it is possible to provide some information on what the society was like for the people who lived at the site. By focusing on the whole site and the patterns of artifacts found within it, we can infer much more about the past than would be possible by focusing on the artifacts alone. At this level we can begin to say something about aspects of the society which are only indirectly represented in the archaeological record, such as whether social ranking was present in the society. To do this, however, substantial areas of the site must be excavated and in most cases, several sites must be excavated. Beyond the artifacts themselves, the relative positions of the artifacts and the features are now of crucial importance in understanding what happened at the site (for examples see Deetz 1967, Fagan 1986 and Sharer and Ashmore 1987)..

Time - answering the big questions about human prehistory

10. The archaeological record spans all of human existence while written records cover only relatively recent events. Major changes occurred in the human species and in human culture which are only understandable through archaeology. The big questions concerning the human experience concern the details of human evolution, the development of human culture as a unique way of adapting to environmental variability, the domestication of plants and animals, and the origin of complex societies and civilizations. Answering these questions requires understanding how people lived during various time periods, but it is more than a large scale study of sites since it also involves models and theories of cultural change and adaptation. Under what circumstances do people change tried and true methods for something new? The basic assumption of the archaeologist is that time is not a causal factor. Change is not inevitable; it must be explained in terms of the environmental and societal factors. There are too many examples of places in the

world where agriculture did not develop or societies did not become complex. Furthermore, the big questions do not involve events, but rather processes. There is no single point in time that can be identified as the beginning of domestication, for example (Hester 1976; Binford 1983). Instead, domestication is a process involving a series of gradual changes in the relationships between people and particular plant and animal species.

11. In general, every archaeologist has one or more of these goals in mind before beginning a research project. Archaeological research in the United States is funded in two ways. Grants from federal and private sources are sought by archaeologists to explore a specific research topic. In this case the research design is often quite detailed and specific. Most archaeological investigations in this country are conducted as a result of some construction project which will disturb or destroy archaeological sites which happen to be present. Federal laws and regulations (and in many states, state laws and regulations) protect significant archaeological sites if the project involves federal funding, federal loan guarantees, or federal permits. Significant sites are defined as those which have the potential to provide important information about the past and are therefore considered to be eligible to be placed on the National Register of Historic Places. Contracts for archaeological investigations require a somewhat more general research design since the objective is to recover information about the site before it is destroyed. Properly gathered, the information can be used to explore a variety of research questions. Since the important research questions of the future are impossible to anticipate fully, preservation of archaeological sites must be a high priority.

Archaeological Sites

12. These goals of archaeology are pursued at archaeological sites. Archaeological sites are typically defined simply as places which contain evidence of human activities (Fagan 1985, Hester 1976, Sharer and Ashmore 1987). Thus defined, archaeology involves developing methods of inferring human activities from the results of those activities. These methods should be as relevant to modern society as they are to past societies and in fact some modern archaeologists study the present (Rathje 1979) while other archaeologists focus on the recent past (Deetz 1977). The evidence of human activities can be roughly subdivided into four categories: artifacts, debris, features, and patterns.

13. Artifacts are objects deliberately created or modified by people. They include things such as pots, projectile points, baskets, clothing, jewelry, and automobiles. Temples, houses, and other structures can also be identified as artifacts. Debris includes stone flakes

produced while making the projectile point, broken bones resulting from a meal, charcoal, and similar items. The important thing about debris is that it has been modified or moved as a result of human activity. Since debris is not inherently useful, more debris is left behind at a site than artifacts. Features are human modifications of the surface of the earth. They include things such as the dark stains left by a decaying post, a pit excavated for storing food or as the basis for constructing a house, a cemetery, and a firepit or hearth. Because features are a part of the surface on which people were living, they must generally be recorded during the excavation of the site and are not brought back to the lab for further analysis the way artifacts and debris are. Features are often identified on the basis of difference in the color or texture of the sediments in which the site is located.

14. Patterns are not items at all but configurations of the artifacts, debris and features at the site. Identifying patterns requires two elements. First, the excavation is conducted with sufficient vertical and horizontal control that materials which are contemporaneous can be identified. In other words, it is not sufficient simply to have the artifacts themselves; it must be possible to place them in a context. The distribution of the artifacts, debris, and features must be recorded in sufficient detail to show that, for instance, animal bones and stone flaking debris are concentrated around a fire hearth. When two or more things are judged to be contemporaneous, they are referred to by archaeologists as being "associated." Even if this control is present, patterns will be difficult to identify if the site has been disturbed by burrowing animals, erosion, or other factors. The second requirement is a model or theory which suggest what configurations of material are significant for understanding prehistoric cultures. The model may be very simple, such as any pattern which is non-random is potentially significant, or it may be very detailed, such as a model which predicts which elements of the skeleton of an animal should be present if the site is a kill site. In recent years the most significant advances in archaeology have been the development of more sophisticated techniques for pattern recognition.

15. Archaeological sites come in many sizes and shapes (Fagan 1985, Hester 1976). A rough classification distinguishes two major groups:

a. Habitation sites
   (1) Seasonal camps
   (2) Permanent settlements (villages)
   (3) Towns and cities
b. Special function sites
   (1) Hunting sites (where animals were killed and butchered)
   (2) Mining sites (where raw materials were gathered)

(3) Cemetery sites
(4) Ceremonial sites
(5) In transit sites (camps for travellers)

Habitation sites are occupied by whole family groups. Special function sites may be occupied only briefly or are occupied by only part of a family group. The list of special function sites provides some of the more common examples, but is not intended to be exhaustive. In addition, sites might be distinguished into those which contain evidence of occupation at several different time periods and those which were occupied only once. The former are more useful for building chronologies and looking at changes over time, but the latter are easier to excavate and are more likely to contain evidence which has not been disturbed by later occupations of the site.

Techniques - Gathering Data

16. While some archaeological sites are located by interested nonprofessionals, most sites are found during surveys in which archaeologists walk along the ground at measured intervals and look for signs of prehistoric or historic activity. These signs may consist of features such as the remains of a chimney which marks the location of an abandoned farmstead or chipping debris left behind when a stone tool was made. Once located, the site is mapped and small shovel test pits may be excavated to determine whether or not archaeological materials extend beneath the surface. At present archaeologists have no economical way of finding sites which are not visible on the surface. Modern surveys in the United States will include geomorphical studies to identify Holocene deposits in the survey area which can be examined for buried sites through backhoe testing. In the United States, site records are maintained for each state, but except for the National Register of Historic Places, there is no national data base of archaeological site information.

17. Remote sensing is being used with increasing frequency in modern archaeological surveys. Although Landsat imagery is capable of locating only the largest sites, vegetation and soils mapping based on Landsat imagery has been successfully employed to develop models which predict the locations of archaeological sites. Lower altitude aerial photography from the Soil Conservation Service and other sources can be used to find sites with structural evidence on the surface (such as abandoned houses, burned rock mounds, or burial mounds) as long as the vegetative cover is not substantial. Side scan radar has been used to locate canals in the tropical forests of Mexico. To locate underwater sites, magnetometer and side scan sonar surveys have been successfully

employed. Remote sensing is also used on the surface of known sites. Proton magnetometers, radar, soil resistivity and metal detector surveys have all shown the potential to help the archaeologist locate features and structures beneath the surface without any excavation. None of these techniques are routinely applied to all sites, partly because many sites in the United States do not contain distinct structures or features of a size that makes it possible for them to be detected using these techniques (Sharer and Ashmore 1987).

18. Often the initial surface appraisal of an archaeological site does not provide sufficient information for the archaeologist to determine its significance. Here significance can mean that the site is eligible for the National Register and the effects of the construction project on the site must be taken into consideration (Fagan 1985, King, Hickman and Berg 1977, Schiffer and Gumerman 1977). Alternatively, significance can mean that the relevance of the site to the research focus of the archaeologist is uncertain. Archaeologists often refer to a limited excavation of a site as "testing" since they are trying to gain additional information about the site. The purpose of testing is to answer a number of questions:

a. When was the site occupied?

b. Does the site contain evidence of more than one occupation?

c. If there are multiple occupations, how well are they separated at the site either vertically or horizontally?

d. Is there evidence that the site was disturbed by water or wind erosion or by burrowing animals after it was abandoned?

e. How well are things such as bone, plant remains, and evidence of features preserved at the site?

f. What is the nature of the site stratigraphy and the sediments/soils contining the site?

Answering these questions and others like them allows the archaeologist to make a recommendation regarding the significance of the site or to make a decision concerning the degree to which the site can provide the evidence sought by the research design of the investigator.

19. A sites is excavated only when the archaeologist is satisfied that it provides information which is relevant to the research questions he or she is asking. Sites which have been determined to be eligible for the National Register are excavated only if a construction project cannot leave them undisturbed. The excavation of an archaeological site involves its systematic destruction. Any materials which are discarded are lost and any observations which are not recorded are also lost (Barker 1977). Although it is often

suggested that a site should be excavated so that everything could be replaced exactly the way it was, this is impossible. Features consist almost entirely of observations made during the excavation. The exact soil textures and colors can never be recreated. Very small constituents of the site such as pollen and microscopic stone flakes are never completely recovered from the site. Site excavation always involves realistic trade-offs between research goals and economic realities. While this is true, it is also true that archaeologists generally recover more material and information from a site than they have the time to fully analyze.

20. Excavating a site involves developing a plan which assures that the observations required by the research design will be made (Barker 1977, Fagan 1985). On a site with several different occupations arranged vertically, a balance must be struck between vertical sections or profiles which show the arrangement of the various occupational strata and horizontal sections or plan views which show the distribution of artifacts and features over a single surface. Horizontal and vertical controls are imposed on the site so that the location of any particular artifact can be recorded with some precision. At the same time, it is common to excavate within units of a standard size (for example, one by one meter to a depth of 10 centimeters). Artifacts recovered within each unit are separated, but the exact location of a particular artifact within such a unit is unknown. This practice provides sufficient locational information to answer a variety of questions, but is far more economical than recording the position of each specimen. The thickness of the standard excavation units varies. It is desirable for the levels to follow natural stratigraphic zones whenever possible. However, in many cases these zones are too gross to provide good control of the vertical distribution of the artifacts. For this reason, arbitrary levels of five or ten centimeters are typically used within natural zones. The research focus of the excavation project will also determine the way in which the excavation units are laid out (Barker 1977, Joukowsky 1980). If the goal is to find out about the spatial extent of a number of different occupations, the units may be scattered randomly or systematically over the site. If the goal is to discover patterns of activities at each level, then the units will typically be clustered into a single large block. To make certain that the recovery of artifacts and debris is not biased by the excavator, the site matrix is often screened through hardware cloth or window screen so that small materials will also be recovered. Columns of sediments are also collected to provide the basis for soil tests, pollen extraction, and snails and other microfauna which can provide evidence of the surrounding environment at the time the site was occupied (Fagan 1983).

Methods - Analysis

21. Once a site has been excavated, a lengthy process of curation and analysis begins. Materials recovered from the site are washed, sorted into gross categories, labelled, bagged, and inventoried. Special samples are sent to various specialized laboratories for analysis. Although some observations can be made only in the field during the excavation, many can only be made in the laboratory through a detailed examination and comparison of the archaeological materials (Fagan 1983, Joukowsky 1980, Sharer and Ashmore 1987).

22. One of the major goals of any archaeological investigation involves dating the site or the various layers within the site. Archaeologists group their dating techniques into two categories: relative dating and chronometric dating (Deetz 1967, Fagan 1983, Sharer and Ashmore 1987). Relative dating techniques provide sequences in which a particular site or material is known to be older than some other site or material, but a calendar date cannot be provided. Relative dating is provided by the stratigraphic sequence at the site since the deeper layers can be assumed to be earlier than the later ones. Relative dating is also provided by the change in artifact styles over time. By analyzing the changes in artifact styles and in the percentages of different types of artifacts, it is often possible to work out a chronological sequence. Again, the sequence does not provide a particular date. Chronometric techniques provide calendar dates for artifacts and the sites with which they are associated. The best known example is radiocarbon dating which makes it possible to evaluate the age of any organic material as far back as about 50,000 years. Charcoal gives the best results, but bone, shell, leather, and plant remains can also be used. Dates can also be provided by other techniques that depend on radioactive decay. One such technique is Potassium-Argon which was used at Olduvai Gorge to date early hominid finds to 1.75 million years ago. Dendrochronology is based on variability in the thickness of annual growth rings in certain trees and has been successfully applied in the southwestern United States. Obsidian hydration involves measuring the thickness of the hydration layer that forms on the surface of obsidian. Other techniques such as thermoluminescence and amino acid racemization are still in the developmental stage and may provide only relative ages. When none of these methods can be used, it is often possible to get an approximate age for the site by comparing the artifacts with those found at similar sites for which dates have been obtained.

23. Much of an archaeologist's time is spent examining the artifacts and debris which have been recovered from the site (Sharer and Ashmore 1987). Some materials can be identified through comparison. Faunal remains, macrobotanical remains, and pollen

can all be identified through comparison with modern species or with fossil specimens which have previously been identified. Once identified, comparisons can be made between the various species present at the site to determine which ones were the most common. It may be possible, for example, to determine the season during which the site was occupied by examining pollen remains or by finding bones of a migratory species. Analysis of the distribution of the anatomical elements present in the site from the various species which provided the subsistence base for the prehistoric inhabitants can provide evidence of hunting and butchering practices. Other bones which can be identified come from the prehistoric inhabitants themselves. Examination of these bones can provide us with information on the demographic structure of the population, life expectancy, and the incidence of certain diseases and traumatic injuries.

24. The results of human activities, the artifacts and the byproducts created whenever an artifact is created can also be analyzed. Here the classificatory problem is more severe since we lack the relatively neat categories provided by the Linnean classificatory system. In fact, each archaeologist will often come up with a somewhat different way of classifying the material. The classification of artifacts is part science, part art, and is strongly influenced by the research questions being considered. Attributes which are relevant for one question may be irrelevant for another. For example, a classification developed to explore changes in the technology of stone tool or ceramic manufacturing will be very different from a classification developed to study the distribution of ethnic groups (Deetz 1967, Fagan 1983, Sharer and Ashmore 1987).

25. For this reason archaeologists often distinguish among the various sources of variation in artifacts. Technological variability includes the aspects of an object which are affected by the raw material used in its construction and by the sequence of manufacturing steps followed to create it. Functional variability includes the attributes of the artifact which relate to its intended use. For example, projectile points have sharp tips while hide scrapers have steep rounded ends. Social variability recognizes that artifacts are often used to communicate things like age, sex, and social class or rank. In other words, artifacts are used to send messages as well as having a utilitarian function. Social variability may include stylistic variations in artifacts which are functionally similar. Finally, ideological variability is another form of communication, but here the message is linked to the mythology and the religious practices of the group. Within our own society, a cross carries an ideological message. At the same time, a wooden cross and a golden cross both carry the same ideological message, but may carry different social messages. Obviously archaeologists are not often able to decode the various social and ideological messages which are embedded in the objects they study, but they must be attuned to the various

sources of artifact variability so that they can design an artifact classification around a particular research question.

26. The synthesis of all the diverse studies conducted on materials from a single site is a major integrative task (Fagan 1983, Sharer and Ashmore 1987). Evidence concerning the environment at the time the site was occupied provides an overall context. Evidence regarding the subsistence base for the group is a natural second step. Analysis of the spatial distribution of the artifacts, debris, and features provides the basis for identifying patterns in those distributions. It is at the pattern level that the archaeologist is likely to have the most success in providing interesting information about past lifestyles and the way in which the society was organized. Patterns may be delineated in either space or time. Patterns in space provide information about settlement plans, the distribution of various activities, and information about social ranking. Patterns in time provide information about how things changed. While archaeology is a poor substitute for ethnography, it is the only way we can find out about the distant past. It is also the only way a single individual can study changes in human society that spanned hundreds or thousands of years. For that reason, the big questions of archaeology focus on things like the development of culture and culture changes which spanned many human generations.

Sampling Issues

27. Very few sites are completely excavated. Even at sites which are completely excavated, information and archaeological materials are lost in the process. All excavations therefore involve some kind of sampling. Furthermore, the archaeological site itself is a biased sample of prehistory. The biases in the archaeological record itself cannot be changed, but they can be recognized and controlled. In the last twenty years archaeologists have increasingly gone into the field to study living societies and observe the formation of the archaeological record in order to better understand the various transformations that occur (see Gould, this volume). The major goal of these studies is to understand how the dynamics of a human society become coded in the static archaeological record. Another way of dealing with biases is to compare material from two or more sites with similar post-occupational histories so that decay processes can be held roughly constant.

28. Because of constraints due to time and funding, archaeologists have increasingly turned to sampling techniques (Mueller 1975). Many large-scale projects now begin with a survey of a sample of the areas under consideration. This sample is often acquired by grouping areas according to soil, vegetation, or topography and then randomly selecting

areas within each group to be surveyed. The sample results can then be used to develop estimates of the total number of sites likely to be present in the area and the number of each type of site.

29. Sampling is also employed at the site level. Since a site can rarely be completely excavated, some selection must be made regarding how much of the site to excavate and which areas within the site will be excavated. Random sampling is rarely employed in these circumstances for several reasons. In the case of stratified sites, the boundaries of all of the occupations below the uppermost one are generally not known and the archaeologist cannot specify the sampling frame in advance. Estimates of the number and density of artifacts are more accurate if a large number of small units are excavated, whereas evaluation of the patterns of artifacts, debris, and features present in the site require that large areas be exposed. Furthermore, the small units which are optimal for artifact density estimates are ineffective for stratigraphic analysis of the various occupational units because it may be impossible to correlate the artifact sequence in one unit with that in another unit on the other side of the site. Because of these difficulties, archaeologists tend to utilize systematic sampling frames at the site level. Systematic sampling is used in the selection of test excavation units. Major block excavations are generally selected to focus on areas where preservation is particularly good or features or structures have been located during testing. Systematic sampling is also used to recover samples of sediments for processing by pollen extraction, soil analysis, or flotation processing to recover very small flakes, carbonized plant remains, and fauna.

30. Sampling is also employed in the laboratory. When the volume of archaeological material is too great to permit a detailed analysis, random or systematic sampling techniques are often used. All materials may be counted and weighed, for example, but only a sample may be subjected to detailed analysis. For example, a sample of the ceramics may be examined for information on tempering and texture. An even smaller sample may then be sectioned for microscopic examination.

31. Although archaeologists are not strangers to sampling, they are not often explicit about the basis for their decisions. While it is a relatively straightforward procedure to determine what sample size is required in order to estimate the density of an artifact type or its size within certain limits, it is much more difficult to determine how large an area of a site must be excavated in order to demonstrate an association between artifact concentrations and features. Since these patterns may be few at any one site, it may be necessary to excavate several sites to confirm a pattern observed at a single site. At present archaeologists are not very adept at providing straightforward answers to seemingly

simple questions such as, "How many sites of this type must be excavated before we can know what there is to know about them?"

Conclusions

32. Archaeology is the study of human society through the use of material remains. On the one hand archaeologists are at a significant disadvantage in studying human behavior since they can only observe the results of that behavior. On the other hand, this very fact forces the archaeologist to look at the big picture, to focus on changes which occurred over hundreds or thousands of years. They have a monopoly on much of the past since there are no written records and no survivors to interview. Over the last one hundred years of archaeological investigations, there has been a steady improvement in both excavation and analytical techniques. This trend will almost certainly continue. A major goal of this conference is to assure that as those new techniques and interpretive frameworks are developed, there will still be archaeological sites around on which to apply them.

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ARCHAEOLOGICAL CONSERVATION AND PROCESSES OF ARTIFACT DETERIORATION

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Introduction

1. For the past 17 years I have been actively involved in the conservation of archaeological material. Most of my work has been with the conservation of material recovered from marine sites, but I have had considerable experience treating material culture from an array of terrestrial sites of many different time periods, cultures and environments across the state of Texas. My obvious concentration on the conservation of material from marine sites should not be considered a handicap, for the conservation problems are compounded when dealing with marine recovered material. Basically, most of the conservation techniques are similar, and if a conservator and a conservation laboratory is capable of treating the vast array of material recovered from shipwreck sites and other waterlogged sites, he is capable of handling any problem presented by material from a terrestrial site.

2. In many respects I differ from many practicing conservators in the United States. I consider myself to be an archaeologist that does conservation; therefore, my approach is somewhat different. As an archaeologist I subscribe to the three main objectives of archaeology:

a. Reconstruct culture history
b. Reconstruct past lifeways
c. Study cultural process

These objectives are achieved through the recovery, analysis and interpretation of archaeological data which consists of

a. Artifacts: in the strictest sense, humanly manufactured or modified objects.

b. Features: artifacts that cannot be removed from the ground such as post holes and pits normally appearing as stains in the soil.

c. Structures: usually houses, buildings or temples and standing above the ground,

but sometimes used to refer to buildings that can be identified from patterns of post holes and other features in the ground.

d. Ecofacts: the food remains such as bones, plants, and seed.

Some archaeologists would add a fifth category:

e. Human skeletal remains.

Archaeological data, then, consists of the patterned distribution of artifacts, features, and ecofacts in time and space. These, with the exception of human skeletal remains, are commonly referred to as material culture.

3. Archaeological conservation is primarily concerned with artifacts and ecofacts. Structures are a different problem and features are seldom conserved; however, I have "preserved" a posthole. When treatment is accorded an object, it can include both conservation and restoration. One should have a clear understanding of their differences. Conservation refers to the process of documentation, analysis, cleaning, and stabilization of an object. The main objectives of the cleaning and stabilization are to protect the artifactual and faunal material and to prevent it from reacting adversely with its environment. Restoration refers to the repair of damaged objects and the replacement of missing parts. A specimen may undergo both conservation and restoration, but in all cases the former has priority over the latter. Restoration should never be initiated without conservation (Coremans 1969). Whereas art conservation often seeks to return a work of art to its original condition, ethnographic and archaeological conservation should seek to preserve the objects's life history at the time of collection (NIC 1984). Restoration is seldom done in archaeological conservation.

Historical Perspective

4. Historically, within the field of archaeology in the United States the treatment of cultural material beyond initial washing and cataloguing is rarely emphasized. As a result, many invaluable artifacts and considerable data are lost, and the archaeological laboratories in the country are busting at the seams with un- conserved or poorly conserved artifacts. Some of the blame for the lack of proper treatment must be leveled at the curatorial staffs of museums and repositories of archeological material that have a responsibility to care for the specimens in their possession; initially, however, the blame lies with archaeologists. It is their responsibility to see that the material which they recover is treated and stored so that it will be available for research long after the field work has been completed and reports have been written. Unlike our colleagues to the

north, in Canada, where proper conservation of recovered material must be arranged before a permit to excavate is granted; this is not the case with most states in the United States. Although an awareness of the need for specimen conservation subsequent to field recovery was stated as early as 1910 (Hodge 1959), little helpful information has appeared in the professional archeological literature. More recent field manuals and papers have only cursorily treated the problem (see for example Hester, Heizer and Graham 1975). This lack of interest by archaeologists is surprising considering that artifacts are one of the basic units of analysis; but major reorientation is occurring. Conservation papers are given in the annual meetings of the Society for Historical Archaeology and in the last year a "Conservation Forum" column has been included in their newsletter.

5. Beginning in the early 1950's there has been considerable increase in interest in the conservation of cultural property, such as portable works of art, books, manuscripts and other objects of artistic, historic or archeological origin, including scientific collections, as well as architectural monuments (Daifuku 1968). Within this period all the major international conservation bodies have been founded, including the International Institute for Conservation of Historic and Artistic Works (IIC), which publishes Studies in Conservation, the major technical journal in conservation, established in London in 1952; and the International Centre for the Study of the Preservation and the Restoration of Cultural Property, founded in Rome in 1959 by the United Nations Educational, Scientific and Cultural Organization (UNESCO). A major reference book, The Conservation of Antiquities and Works of Art by H.J. Plenderleith, came out in 1956. As a result of these developments, conservation started emerging from a craft oriented specialty into a formal scientific discipline.

6. The increasing recognition of the significance of cultural property and its conservation is having an impact on anthropological archaeology. Now, at several universities in the United States, courses in conservation are being offered by archaeology/anthropology departments. As a result, there is an increasing appreciation of the value of conservation training and the responsibility of the archeologist to see that recovered material is properly curated.

7. At present, however, many archaeologists do not have the necessary experience or training to handle conservation problems commonly encountered in the field. To compound the problem, few archaeology programs or laboratories have adequately trained staffs, properly equipped laboratories, or sufficient funds and time. Ideally, before field work is initiated, conservation problems should be anticipated and appropriate plans made. A field laboratory often satisfies all the requirements; in other cases a better equipped conservation laboratory is required.

8. There is a major problem in regard to archaeological conservation. Where does one go to find or hire a trained archaeological conservatory? In the United States this remains a big problem. In Texas we are fortunate in having three conservation laboratories that process archaeological and ethnographic material. Most states do not have a single conservation laboratory and are not within 500 miles of one. Many of the established laboratories do not accept outside work. It is for this reason that the National Conservation Advisory Council (NCAC 1979) designated archaeological conservation as an area of major concern in the United States and cited the critical need for more trained conservators. In 1987, the need is just as critical and still no formal training in archaeological conservation exists in the United States. There are three degree granting academic training programs in the United States which graduate a maximum of 30 students a year. Most of these are in fine arts, decorative arts, paper, or textiles. Archaeological conservation is not a major concern of any of the three; however, two have provisions for students wanting to specialize in archaeological conservation. What this means is that there is going to continue to be a shortage of archaeological conservators and archaeologists wanting to provide proper conservation to their excavated material and are not going to be able to do it.

Tenets of Conservation

9. Conservation should not detract from the natural appearance of the object nor alter any of its scientific attributes since artifacts are a primary unit of study in archaeology. The conservator should strive to process specimens so that they retain as much diagnostic data as possible and yet remain chemically stable. For example, every attempt should be made to preserve as much as possible of the original surfaces, form and dimensions. In addition, all treatments should be reversible. This last requirement recognizes that a conservation treatment may not last indefinitely nor remain superior to all future techniques. No conservation process can be assured to last indefinitely and depending on storage or display environment, some will have to be retreated at some time in the future. The objective of any conservation technique is to delay this reprocessing as long as possible and to make any necessary retreatment brief. If the original treatment is reversible, the option to retreat is always open and the continued preservation of the material is assured.

10. When objects are treated, the basic attitude and approach should be cautionary and similar to that espoused by Plenderleith and Werner (1971). Basically they state that the past history of an artifact may impart features of significance pertaining to age and provenience which can validate its authenticity. Therefore, a preliminary examination of

the object needs to be made to determine a course of action that will preserve the integrity of the specimen and maintain any significant attributes or any features relating to its manufacture, microstructure, or life history. In some cases, a corrosion layer may contain valuable archaeological data, in which case it should be preserved and not indiscriminately removed. Only in those instances where the corrosion is unstable, conceals underlying details or is aesthetically displeasing should it be removed. Above all, one should heed the cautionary advice given by Plenderleith and Werner (1971), "This work calls not only for knowledge, foresight, ingenuity, and dexterity, but for infinite patience. It should never be hurried."

11. The concern for the recording and preservation of the basic data derived from any given piece is essential and needs to be expressed by all laboratories which process archaeological material. In archaeological conservation there is often more to consider than just preservation of individual artifacts. One duty of the conservator is to stabilize the artifact so that it retains its form and diagnostic attributes. For this reason soot, food residue, scratch marks, and dents are not removed from an object for they are part of the story that the object has to tell. When treating archeological material that requires documentation of context, as well as preservation, the documentation demands equal emphasis and first priority. In order to garner as much information from the material culture the conservator working on archaeological material must work closely with the investigating archaeologist, analytical scientists, and a number of specialists in other disciplines (NIC 1984). I maintain that at present any well-planned archaeological project should try to anticipate the conservation requirements in the field and include properly planned conservation prior to and after the excavation. No one should be forgiven if conservation is cursory or slighted. If conversation plans are not included, as much data may be lost as is gained.

12. One of the major problems that continues to haunt archaeological conservators is the lack of basic research on deterioration studies in archaeological sites. Studies are underway on the rates and kinds of corrosion of metal artifacts on shipwreck sites in salt water, but I do not know of any comparable studies being conducted on buried terrestrial sites. In lieu of concrete information on the rate and kinds of deterioration affecting material culture in archaeological sites, we have to rely on related studies from the physical sciences, such as corrosion chemistry.. Many of the factors that affect the rate of deterioration of cultural material are physical, geological and biological processes which are discussed elsewhere in this workshop. See Dr. Gentry Steele's discussion on zooarchaeology and Dr. Mike Water's paper on geoarchaeology, for discussion about compaction and other geological and physical processes. I will concentrate my discussion

on the corrosion of metals in buried archaeological sites and to some extent, bone, wood, ceramics, and glass.

13. Time does not permit a detailed discussion of the corrosion of all the metals commonly found in archaeological sites - mainly historic period sites - in this short presentation, so I will concentrate on the most important aspects of metal corrosion.

Metal Corrosion

14. During most of the history of metallurgy only a relatively few metals have been used. The metals of antiquity, iron, tin, copper, lead, silver and gold are those which were recognized and intentionally utilized with consistent regularity to manufacture tools, weapons, ornaments, hardware and other paraphernalia. Each of these was used individually and in combination with the others, or zinc, to form more serviceable alloys such as bronze, brass and pewter.

15. From the moment of manufacture the various metals and their alloys, except for gold, react with their environment and begin a corrosion process that converts them to more stable compounds. Basically, metals do not like to be metals and constantly want to convert to a more stable steady state, which is any number of stable minerals. Before competent conservation techniques can be applied to a metal artifact it is essential that the conservator be aware of the corrosion products that result from exposure to different environments. The nature of the corrosion products determines the technique and procedures that can be effectively used.

16. The corrosion of metals can be discussed in terms of terrestrial environments with temperate, tropical, and desert subdivisions as well as aquatic environments with salt and fresh water subdivisions. A more simplified approach, and more to the point, is to look at the corrosion resulting from the interacting effects of wet, dry, aerobic, and anaerobic environments, i.e., the presence of oxygen and moisture. In any environment moisture, porosity, temperature, pH, and the presence of aggressive anions, such as chlorides are critical variables that determine the rates and types of corrosion.

Ferrous metal corrosion

17. Iron is usually the most prevalent metal in archaeological sites. Of all the metals of antiquity this one presents the conservator with the most ponderable problems because of the variety of conditions and environments under which corrosion can occur and the number and complexities of the corrosion products. Moreover, the corrosion processes are applicable to other metals and make iron a useful introduction to all metallic corrosion. The following relies heavily on Evans (1963), Potter (1956), and Pourbaix (1966).

18. Electrochemical corrosion. Iron buried in the soils or lying on the ground surface exposed only to ground and air moisture corrodes essentially by an electrochemical process. The corrosion of iron in sea water proceeds in somewhat the same manner but is greatly accelerated because water becomes more corrosive as the salt content increases. For example, iron corrodes five times faster in sea water than in soil and ten times faster in sea water than in air (Cornet 1970). Iron buried in the soil, then corrodes, at a minimum, two times faster than in air.

19. For iron artifacts buried in the ground, pitting is generally a prominent feature of the corrosion process, and this environment tends to be chemically reducing, forming soluble ferrous ions which often diffuse some distance away from the iron surface. When iron is buried in an aerobic soil or exposed on the surface to the air, the ferrous ions initially formed in the corrosion process oxidize to ferric ions which results in layers of ferric oxide scale on the metal surface. This ferric oxide scale tends to form layers that may crack and spall due to the differences in the thermal expansion coefficients between the ferrous and ferric corrosion products and the metal. Alternatively, the corrosion products may inhibit additional corrosion because they form a protective film. Air-oxidized artifacts occupy more volume than the original metal, and usually have obvious layers of ferric oxide scale. If salts, such as sodium chloride, are present in the water, or in the soil, a very conductive solution is formed and electrochemical corrosion is accelerated. Based on my experience, I think it is safe to say that most of the small iron artifacts buried in an aggressive site environment will be completely corroded and destroyed in two hundred or less years. Larger artifacts will last longer.

20. In electrochemical corrosion, a galvanic cell can be created when two different metals, or different areas on the same metal, are coupled by means of an electrical or ion-conducting electrolyte. The result is an electrochemical reaction. In essence, electrochemical corrosion is reserved for those processes where a current flows between anodic and cathodic areas situated at different parts of a metallic surface or between two different metals of the same or different material.

21. The metals of antiquity are arranged according to their relative chemical activity or electrode potential into an electromotive series of the metals:

Noble End (cathodic)	Electrode Potential
Platinum	
Gold	+1.50
Silver	+0.799
Copper (cuprous)	+0.552
Copper (cupric)	+0.337

Bronze	
Brass	
Hydrogen	0.0
Lead	-0.126
Tin	-0.136
Iron (ferrous)	-0.440
Steel	
Zinc	-0.763

Base End (anodic)
(modified from Evans 1963, end paper)

The least active metals are at the top and the most active ones are at the bottom. The more negative the electrode potential is, the more active the metal is, and there is a greater tendency for the atoms to lose electrons and form positive ions which go into solution. When the ions of a metal go into solution, the parent metal always becomes negatively charged, regardless of its electrode potential sign. When two metals form an electrochemical cell, the metal having the more negative reduction electrode potential in the electromotive series becomes the anode. It loses electrons and forms positive ions which go into solution. The more noble or positive metal in the cell forms the cathode and is given cathodic protection, while the anodic metal is preferentially corroded in any resulting electrochemical reaction.

22. The primary anodic reaction of electrochemical corrosion of iron is the production of ferrous ions. The secondary stage, the oxidation of the ferrous ion compounds to a ferric state, is modified when the supply of oxygen is restricted as in stagnant water or in the soil. Intermediate oxidation products of ferrous hydroxide such as hydrated magnetite and black magnetite are formed (Evans 1963, Potter 1956). Depending on the environment, the corrosion products can take on a variety of physical forms, state of division, and hydration. It is common to find corroded iron with an outer layer of hydrated ferric hydroxide (common rust) which has restricted the supply of oxygen to the ferrous hydroxide briefly formed at the surface of the metal. This results in laminated corrosion layers consisting of an inner layer of black magnetite, a thin layer of hydrated magnetite and an outer layer of hydrated ferric hydroxide.

23. Anaerobic corrosion. The rate of corrosion of iron buried in the soil, away from a ready supply of oxygen would normally slow down, but corrosion may accelerate because of the presence of sulfate-reducing bacteria. These bacteria play a large part in the corrosion of metals. They adversely affect metals in salt water, fresh water and buried in the soil under anaerobic conditions (Evans 1963, Leigh 1973, Pearson 1972). It is now generally acknowledged that the various species of these bacteria play a large part in the chemical corrosion of iron in waterlogged anaerobic environments. In fact, as much as

60% of the corrosion of iron in salt water can be attributed to bacterial action (Pearson 1972). It accounts for most of the rapid corrosion of buried iron and steel pipelines in waterlogged clay soils in England (Farrer, Biek, and Wormwell 1953).

24. Sulfate-reducing bacteria, particularly the strains known as *Sporovibrio desulphuricans* (Pearson 1972) and *Desulphovibrio desulphuricans* (Farrer, et al. 1953) are commonly found in salt water, fresh water, and waterlogged soil. The decaying organic material consumes oxygen and creates localized anaerobic environments. Sea water has a large supply of sulfates and under aerobic conditions these bacteria utilize hydrogen to reduce the sulfates to sulfides as a metabolic by-product. In this process the hydrogen that accumulates on the iron as a cathodic product polarizes the cathode in an oxygen-free environment. The polarization of the cathode ordinarily halts the electrochemical corrosion process. However, the utilization of hydrogen in the metabolism of the bacteria depolarizes the cathodic areas of the cell and allows the corrosion to continue unabated. In addition, the hydrogen sulfide formed as a metabolic by-product reacts not only with iron, but all the metals of antiquity except gold and accelerates the corrosion process. The hydrogen sulfide reacts with the ferrous ion from the anodic areas to produce ferrous sulfide and ferrous hydroxide, two major corrosion compounds of iron associated with objects recovered from the sea (Leigh 1973, Pearson 1972).

25. Generally speaking, iron is less corrosive in an environment with a pH above 8, if it is free of chlorides. Below a pH of 8, the presence of oxygen will increase the rate of deterioration; the corrosion will be localized and the attack can be intensive. The protection of iron is difficult or impossible at a pH below 8, relatively easy at a pH above 8, and very easy between pH 10 and 12. If the environment contains any aggressive anions (i.e. any negatively charged ion that readily reacts with iron such as chlorides and sulfates) a higher pH is required to alleviate the corrosion process.

26. Once iron has been removed from an archaeological environment the corrosion process will continue, and even accelerate, unless certain precautions are taken. It is essential that they be properly stored to prevent further corrosion. If the iron object is exposed to the air or to an un-inhibitive solution, the ferrous compounds can oxidize to a ferric state which occupy a greater volume and scale off the surface. Just this process can disfigure a piece and eventually destroy it. The greatest damage, however, is caused by the ferrous chlorides which oxidize to ferric chloride and ferric oxide. The ferrous chloride and ferric chloride combine with water to form hydrates. It is these hydrated chlorides that cause the trouble. On exposure to moisture and oxygen they hydrolyze to form ferric oxide or ferric hydroxide and hydrochloric acid. The hydrochloric acid in turn oxidizes the uncorroded metal to ferrous chloride and hydrogen, or ferric chloride and water. The

corrosion process is cyclical, continuing until no metal remains.

Nonferrous metal corrosion

27. Cupreous metal corrosion. I use the term cupreous metals to designate all the metals that consist of copper or copper alloys that contain copper as the predominant metal such as bronze (an alloy of copper and tin) and brass (an alloy of copper, zinc and often lead). The term does not imply a valence state as does cupric-divalent copper, or cuprous-monovalent copper. The cupreous metals are relatively noble metals that frequently survive adverse conditions, including long submersion in salt water, that often completely oxidize iron. Copper is corroded in oxidizing and highly alkaline environments. In neutral to slightly alkaline conditions the corrosion of these metals is checked by an oxide film. When corroded, they react with the environment to form similar alteration products such as cuprous chloride, cupric chloride, cuprous oxide and the aesthetically pleasing green and blue colored cupric carbonates, malachite, and azurite (Gettens 1964). In waterlogged sites with dissolved chlorides, cuprous chloride is formed and in anaerobic environments where sulfate reducing bacteria are prevalent cuprous sulfide is the most common corrosion product. All of this is a very simplified explanation, for the mineral alterations in the copper alloys, bronze and brass, is more complex than those of just copper.

28. The first step in the electrochemical corrosion of copper and copper alloys is the production of cuprous ions. These in turn combine with the chloride in the site environment to form cuprous chloride. Cuprous chlorides are very unstable mineral compounds. Once cupreous objects are recovered and exposed to air, they inevitably continue to corrode chemically by a process commonly referred to as bronze disease. In this, cuprous chloride in the presence of moisture and oxygen is hydrolyzed to form hydrochloric acid and basic cupric chloride (Oddy and Hughes 1970). In the presence of air the hydrochloric acid in turn attacks the uncorroded metal to form more cuprous chloride. The reactions continue until no metal remains. Any conservation of chloride-contaminated cupreous objects requires that the chemical action of the chlorides be prevented by removing the cuprous chlorides or converting them to harmless cuprous oxide.

29. Silver corrosion. Silver is a very noble metal and is often found in a native state combined with gold, tin, copper and platinum. It is stable in aqueous solutions of any pH as long as oxidizing agents or complexing substances are not present. Furthermore, it is not attacked appreciably by dry or moist air when the air is free from ozone, halogens, ammonia and sulfur compounds (Pourbaix 1966, Plenderleith and Werner 1971). Silver is particularly susceptible to the effects of the sulfide radical. This is most evidenced by

tarnish on silver objects when exposed to sulfur in any form, but especially hydrogen sulfide and also sulfur dioxide which can convert to sulfuric acid. When corrosion does occur, few mineral alteration products are produced. In the case of relatively pure silver, silver sulfide and silver chloride are formed. In the case of base silver alloys with significant amounts of copper, the copper corrodes preferentially, forming cuprous oxide, cupric carbonate, and cuprous chloride.

30. In a buried archaeological environment, where soluble chlorides are present, silver chloride can be expected. In environments where there is an abundance of soluble sulfates and oxygen-consuming, decaying organic matter which creates an anaerobic condition, sulfate-reducing bacteria utilizes the available sulfates to form hydrogen sulfides as a metabolic product. The hydrogen sulfide reacts with oxidized silver to form silver sulfide. The overall reaction proceeds in the same process as described earlier for iron.

31. Regardless of whether the corrosion products are silver chloride or silver sulfide, both are stable and do not take part in any further corrosive reaction with the remaining silver. In fact, the two minerals impart some degree of protection from further corrosion to the metal. They also often provide an aesthetically pleasing patina which is often desirable and is deliberately preserved. It is only when the corrosion products are disfiguring and hide underlying detail that there is any reason to treat silver artifacts with these two corrosion compounds or patinas.

32. Tin, lead and lead alloy corrosion. Tin articles were seldom made; this metal was used most often in various alloys, especially in combination with copper for bronze. Gettens (1964) notes that tin seldom survives because of the transformation of the tin by direct intercrystalline oxidation to mixed stannous and stannic oxide or by allotropic modification to a loose powdery gray tin, commonly referred to as "tin pest." It is known that sodium chloride also stimulates the corrosion of tin.

33. Lead is commonly found in archaeological sites where it was used for shot, weights, cannonballs, sheeting, and stripping. Lead is a stable metal in neutral or alkaline solution free from oxidizing agents especially if carbonates are present in the water (Pourbaix 1966). Lead is very resistant to atmospheric corrosion and even during prolonged exposure under most archaeological conditions, basic lead carbonate and lead oxides are formed which form a protective layer that prevents further oxidation. Lead chloride and lead sulfide are also common.

34. The presence of organic matter and decaying wood in waterlogged, anaerobic environments, both aquatic and terrestrial, can create anaerobic conditions conducive for the metabolism of the sulfate-reducing bacteria which readily reacts with the lead to form lead sulfide. If soluble chlorides are in the environment lead chloride may be formed.

35. Most of the lead corrosion products, except white lead, do not adversely affect the artifact after recovery. They may be unsightly or even disfiguring, but they do not take part in chemical reactions that attack the remaining metal. The objects need to be cleaned for aesthetic reasons and possibly to reveal surface details under the corrosion layers. The corrosion products themselves are stable.

36. Lead alloys such as old pewter, which was formerly an alloy of tin and lead, oxidizes to the same compounds as the two parent metals. In archaeological sites the condition of different pewter pieces varies widely, primarily because of different local conditions and varying percentages of tin to lead. Various combinations of lead carbonate, lead oxide, lead sulfide, lead chloride, and tin oxide are possible. Old pewter objects often have wartlike blisters on the surface of the metal which possibly result from localized contaminations of salts (Plenderleith and Werner 1971).

37. Gold corrosion. Gold, being a relatively inert metal, undergoes minimum corrosion. It is the copper and/or silver-base gold alloys that easily corrode, resulting in the same silver or copper corrosion compounds leaving an enriched and possibly weakened gold surface.

Metal corrosion summary

38. The preceding discussions on metal corrosion are necessarily brief and primarily refer to those corrosion products most commonly found on metals recovered from salt water. One observation that has become apparent is that the presence of decaying organic material or wood that is in direct association with most metals has an adverse effect on them. Apparently this results from the fact that as any organic material decays it consumes oxygen, thus creating an anaerobic environment that stimulates the establishment of sulfate-reducing bacteria. The hydrogen sulfide that forms as a metabolic by-product of the bacteria reacts with the metal and accelerates the corrosion process, forming various metal sulfides. This corrosion reaction is most evident on iron, silver and lead when it is in direct contact with wood.

Bone and Ivory

39. In both bone and ivory, the main inorganic constituents are calcium phosphate associated with carbonate and fluoride along with organic tissue called ossein which constitutes at least 30% of the total weight. It is often difficult to distinguish between the two unless examined microscopically. Both are easily warped by compaction, moisture, and heat and are decomposed by prolonged action of water. In buried archaeological sites where moist conditions prevail the ossein is decomposed by hydrolysis and the inorganic

framework is disintegrated by acids. In waterlogged sites they are converted to a sponge-like material. Bone/ivory from a salty environment absorb soluble salts that will tend to crystallize out, breaking up the specimen. In arid sites they become dry, brittle and fragmented. In some circumstances they become fossilized as the ossein is replaced by silica and mineral salts. Archaeological bone and ivory can only be cleaned and strengthened and stabilized - satisfactory restoration is often impossible.

Wood Deterioration

40. Being of organic origin, wood normally decays under combined biological and chemical attack when buried in the ground. It can, however, survive prolonged exposure to the extremes of total dryness or complete wetness. In anaerobic waterlogged environments there are profound chemical changes and alterations in the composition and microstructure, resulting in great loss of strength while retaining its overall shape and form. In other environments wood decays from 1) physical action (changes in temperature, fluctuations in relative humidity, etc.), 2) insect attack and rodent attack, and 3) fungal/bacterial decay. By far fungal decay, along with anaerobic bacteria, plays the largest role in the break down of wood. Fungal decay can be eliminated as long as the wood is kept in a relative humidity less than 65%. When wood decays there is considerable loss in physical strength and it must be consolidated.

Waterlogged wood

41. Wood, like other organic material, can survive extremely well in waterlogged environments; however, the conservation requirements are compounded. The tannin in woods, such as oak, protects the wood from degradation, and allows some woods to survive in good condition. In all wood, including oak, after long periods in wet soil, peat bogs and marine sites, bacterial action causes a degradation of the cellulosic components of the cell walls. In general the water soluble substances such as the starch and sugar disappear from the wood first, along with mineral salts, coloring agents, tanning matters and other bonding materials. In time, through hydrolysis, the cellulose in the cell walls disintegrates, leaving a lignin network to support the wood. Even the lignin will break down over a long period of time. As a result of the disintegration of the cellulose and lignin, the spaces between the cells and molecules increases and the wood becomes more porous and permeable to water. All the deteriorated parts, all cell cavities and intermolecular spaces are filled with water. The remaining lignin structure of the wood cell and the absorbed water preserves the shape of the wood. The loss of the finer cellulose tissue does not cause much alteration in the gross volume of the wood, but the porosity is increased and the wood absorbs water like a

sponge. As long as the waterlogged wood objects are kept wet they will retain their shape. If the wood is exposed to the air, so that the excess water is allowed to evaporate, the surface tension forces of the evaporating water will cause the weakened cell walls to collapse, causing considerable shrinkage and distortion. For example, freshly cut, sound wood will, through water loss, shrink ca. 3-6% radially, 5-10% tangentially, and 0-0.5% longitudinally. Oak shrinks 4% radially and 8% tangentially when air dried after cutting, while waterlogged oak can shrink 12% radially and ca. 24% tangentially. The amount of shrinkage is dependent upon the degree of disintegration and the amount of water present.

42. The conservation of waterlogged wood is a twofold problem that involves (1) the removal of the excess water by a method which will prevent any shrinkage or distortion of the wood and (2) incorporation of a material into the wood which will consolidate and confer mechanical strength to the wood.

Pottery

43. Generally coarse earthenware, aboriginal indian pottery recovered from archaeological sites requires only minimum treatment if they are well fired. Fragile, poorly fired pottery, which is characteristic of many regions, such as the Gulf Coast of Texas, is easily warped and may be very soft with friable surfaces when buried in the soil.

44. Earthenware ceramics, including all the historic European and Indian types, excavated from any site where soluble salts are abundant may become saturated with the salts and/or the surfaces become covered with insoluble salts such as calcium carbonate and calcium sulfate. The soluble salts (chlorides, phosphates and nitrates) must be removed for the pottery to be stable. The soluble salts are hygroscopic and as the relative humidity rises and falls the salts repeatedly dissolve and crystallize. The salts eventually reach the surface of the pot where extensive crystallization takes place, exfoliating the surface of the pot and eventually breaking it up through internal stresses. The glazes of European slipwares and the tin enamel wares can be severely altered and even destroyed by the action of soluble salts absorbed into the body of the sherd. In other instances, masses of needle-like crystals can cover the surface, hiding all detail. Well fired ceramics such as stoneware and porcelain are not affected by soluble salts, because they are impervious to moisture.

Glass Deterioration

45. Glass is usually the most stable of archaeological materials, but it can undergo

some complex disintegration especially 19th century glass. Ideally, glass should consist of 70-73% silica, 16-22% alkali (soda ash (sodium carbonate) or potash (potassium carbonate, usually derived from wood ash)) and 5-10% flux (lime (calcium oxide)). Soda-lime glass is the most common glass throughout the history of glass making. Soda glass is characteristic of southern Europe where it is made from crushed white pebbles and soda ash derived from burnt marine vegetation. Potash glass is more characteristic of inland Europe where it is made from local sands, and potash derived from wood ash and burnt inland vegetation. A little salt and minute amounts of manganese is added to make the glass clear, but potash glass is less clear than soda glass. Most early glass is green because of iron impurities in the glass. The alkali lowers the melting point of the sand and the flux facilitates the mixture of the components. As long as the mixture is kept in balance, glass is stable. Problems arise when an excess of alkali and a deficiency in lime (calcium oxide is used as a stabilizer) is used in the mixture, for the glass will be especially susceptible to attack by moisture.

46. At our present state of knowledge, the decomposition of glass is imperfectly understood, but most glass technologists agree that it is essentially a preferential leaching and diffusion of alkali ions (Na & K) across a hydrated porous silica network. Sodium ions are removed and replaced by hydrogen ions which diffuse into the glass to preserve the electrical balance. The silicates are converted into a hydrated silica network through which sodium ions diffuse out. In water, especially salt water, the sodium and potassium carbonate can leach out leaving only a fragile, porous hydrated silica (SiO_2) network. This causes the glass to craze, crack, flake and pit giving the glass a frosty appearing surface. In some cases there is an actual separation of layers of glass from the body.

47. Decomposed glass often appears laminated, with iridescent layers on top of decomposed glass - which is the hydrated silica network. Glass retrieved from an acid environment often has an iridescent film which is formed by the leached silica layers. The alkali which leaches out is neutralized by the acid and fewer hydroxyl ions are available to react with the silica. This causes the silica layer to thicken and become gelatinized as the alkali leaches out. Glass excavated from an alkaline environment is less likely to have laminated layers because there is an abundance of hydroxyl ions to react with the silica network. Normally a protective layer does not form on glass exposed to alkaline solutions. The dissolution of the glass proceeds at a constant rate. The alkali ions are always extracted in excess of the silica, leaving an alkali deficient layer which continually thickens as the deterioration moves deeper into the glass.

Interaction of Conservation and Archaeology

48. Archaeology and conservation have a symbiotic relationship. Conservation provides archaeology with archaeological data, and archaeology contributes material to be processed which also can be used for research and experimentation in conservation. Treating of archaeological specimens makes it possible for the conservation laboratory to contribute valuable information to the technology of conservation. In addition to utilizing established preservation techniques, new procedures can be tried on unimportant or numerous objects and the more successful ones can then be applied to museum and art collections. The operations of the conservation laboratory should be included in the research design and the budgeting of archaeological excavation projects. Scheduling also is important. The conservation laboratory has to have time to process the material to coincide with the report schedule. From the time the processing begins, the laboratory has a continuous input, providing data to be incorporated in the report. There is a continuing interplay of ideas between the conservator and the archeologist throughout the processing, and the final report must await final conservation.

49. From the earlier presentations it is obvious that excavation of an archaeological site is not good archaeology unless the recovered material is processed by a conservation laboratory whose trained personnel have an archaeological perspective, a familiarity with material culture, and awareness of the problems and complexities of marine archaeological conservation. Archaeological conservation should be considered an indispensable archaeological technique where marine archaeology is concerned.

50. In more general terms, conservation should be carried out in other kinds of archaeological projects as well. Proper conservation should be anticipated and planned at any site where metal artifacts are found and in any site in arid or specialized environments where perishable materials are recovered. The material from most terrestrial sites in the United States do not require conservation, thus not necessitating a close association with a conservation laboratory. In some instances there may be exceptional finds that cannot be anticipated, and the services of a conservation laboratory can suddenly be required.

51. With the continuing increases in cost of utilities, equipment, chemicals, and labor, it is not economically feasible to treat every artifact from a site. The decision as to what to treat or not to treat must be worked out with the investigating archaeologist. Factors such as budget, facilities, and time are important considerations. In lieu of total conservation, photographs and scaled drawings will have to suffice for the more common specimens and even for some of the less ordinary pieces.

Summary

52. In archaeology, we normally take the site as it comes, accepting the prevailing environment, positive or negative, and the material that is preserved in it. The artifacts and ecofacts are recovered and conserved. The question of preserving a site by burying creates a lot of questions, as well as thoughts. Obviously, there is no one environment that is conducive for preserving all the material culture of a site. For now we will not even consider the preservation of features which are usually just stains in the soil. An environment for protecting one material assemblage of a site is not necessarily conducive for preserving another assemblage of the site.

53. If a site is buried for protection and preservation for the future, we will have to know what conditions are going to be created and what condition is going to predominate. From this we should be able to say what will be preserved in those given conditions and what will be adversely affected. In some cases, it may be possible to create conditions chosen to protect a given component of a site. But, of course, this will create other problems because depending upon the research problems, the questions being asked and the types of analyses to be done, each person is going to have a different opinion as to what should be preserved.

54. The deterioration of any archaeological material, including both metal and organic material, is accelerated by fluctuations - the switching back and forth between wet and dry, influxes of soluble salts, alterations in pH, etc. If a site can be buried in such a way that any changes are buffered and a more stable steady state is created, then the deterioration of the archaeological material will be lessened. This is true if there are no adverse effects caused by raising or lowering the water table, by changing the drainage, increasing soluble salts, causing erosion or other factors that may adversely affect the site. If a site is already waterlogged, it must be kept waterlogged. In some instance, if a non-waterlogged site is buried and is kept waterlogged then, in most instance, any organic material in the site in a condition to be preserved, is going to be preserved, but the conservation problems, if and when the site is excavated are going to be compounded. It is very critical that fluctuations be eliminated as much as possible.

55. For the metal assemblage of a buried archaeological site, the critical variables are moisture, porosity of the matrix or surrounding soil, pH, soluble chloride, anaerobic conditions, the prevalence of sulfate reducing bacteria and temperature. In the absence of moisture, metal cannot corrode. In the presence of moisture with soluble salts, the corrosion rate is increased because of electrochemical corrosion. In certain anaerobic

environments, the creation of hydrogen sulfide created by sulfate reducing bacteria will readily attack all the metals of antiquity.

56. I can see some instances where burying a site for preservation and protection would be beneficial. But it remains very difficult to try and determine the effects - positive and negative - that are going to affect the different materials in an archaeological site.

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ZOOARCHAEOLOGY, TAPHONOMY AND PRESERVATION OF THE FOSSIL FAUNAL ASSEMBLAGE

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1. The fundamental aims of archaeology are to understand the history of humanity, how humans behave, how human behavior changes over time, how humans acquire the resources they need to survive, and how humans evolve as biological organisms. The data to answer these questions come from the examination of material remains left by humans, the biological remains of the humans themselves, and the context within which these remains are found. The data which archaeologists use may come from a single archaeological site, a collection of related sites or a geographical area where sites exist.

2. The types of materials recovered from archaeological sites can be divided into a variety of assemblages, each assemblage consisting of materials which share common features. Traditionally, archaeologists recognize assemblages composed of: 1) structural features (physical structures such as houses, firepits, storage chambers, etc. which have been built or modified by humans); 2) lithics (tools made of stone); 3) ceramics (tools and ornaments made of clay or glass); 4) bone and shell artifacts (tools and ornaments made from animals remains); 5) botanical remains; and 6) faunal remains associated with the site. Collectively, the remains in these last two assemblages (the plant and animal remains), if they have not been obviously modified by humans are identified as ecofacts, rather than artifacts.

3. Zooarchaeology is that discipline within archaeology which concentrates upon interpreting human behavior, ecology and evolution from an examination of the faunal remains. Typically (but not necessarily invariably or exclusively) these faunal assemblages are found in archaeological sites. The concern of this review is threefold: 1) to provide a thumbnail sketch of the discipline of zooarchaeology emphasizing the questions zooarchaeologists attempt to answer through an examination of faunal remains; 2) to examine known factors which alter the preservation of animal remains in ways that hamper interpretations of human behavior, ecology and evolution; and 3) to assess the impact site burial will have on the preservation of faunal remains. Since human biological remains preserved in sites are composed of the same biological materials as faunal remains, the issues addressed here concerning preservation of animal remains are generally pertinent to human biological remains as well.

Zooarchaeology as a Discipline

4. Zooarchaeology is a relatively new discipline, particularly in North America. The last decade saw the first publication of an historical review of North American zooarchaeology (Robison 1978). Only three comprehensive bibliographies emphasizing North American contributions to zooarchaeology have been published (Bogan and Robison 1978, Lyman 1979, Olsen 1961). And, only a handful of texts summarizing the field of zooarchaeology have been written in English and widely distributed in North America (Chaplin 1971, Cornwall 1956, Hesse and Wapnish 1985, Klein and Cruz-Uribe 1984, Olsen 1971, Ryder 1969, Ziegler 1973). In fact, zooarchaeology is so young that practitioners are still struggling with the question of what to call the discipline (Olsen and Olsen 1981, Bobrowsky 1981).

5. In spite of the recency of the coalescence of the discipline individual scholars have been reporting analyses of faunal remains recovered from archaeological sites since the nineteenth century. Robison (1978) reported that Edward E. Cope listed 17 species of vertebrates recovered from a site in Maryland in 1875, J. W. Fewkes reported on Pacific coast shells recovered from archaeological ruins in Arizona in 1896, and G. F. Eaton reported on the fauna recovered from an archaeological site on an island off the Atlantic coast in 1898. It is interesting to note that two of the basic interests of zooarchaeologists, reconstructing prehistoric human diets and human use of faunal remains as material goods, are reflected in these earliest works. It is also interesting to note that these earliest works represent isolated papers on the topic by each scholar, and reflect only casual interests in zooarchaeology for the researchers.

6. It was not until the first half of the twentieth century that a handful of scholars began to devote more than a cursory interest in the field. Of these early scholars F. C. Baker (1923, 1930, 1931, 1932, 1936, 1941 and 1942) was the most productive scholar, and his works included analyses of both molluscan and vertebrate fauna recovered from sites. Other scholars during this period were Gilmore (1946a, 1946b, 1947, 1949) who examined mammalian remains, Hargrave (1938, 1960, 1965, 1970) who examined avian remains and Wintenberg (1908, 1919, and 1924) who examined molluscan remains from archaeological sites as did Baker.

7. It is also noteworthy that during this period these scholars and others wrote some of the first articles emphasizing the value of zooarchaeaological research, and establishing the basic goals of zooarchaeology. Examples of these papers which began to establish zooarchaeology as a discipline are Gilmore's "To Facilitate Cooperation in Identification

of Mammal Bones from Archeological Sites" published in American Antiquity (1946) and "The Identification and Value of Mammal Bones from Archeological Excavations" published in the Journal of Mammalogy (1949), C. Hart Merriam's "Why Not More Care in Identification of Animal Remains" published in American Anthropologist (1928), Wintenberg's "Archaeology as an Aid to Zoology" published in Canadian Field Naturalist (1919), and Hargrave's "A Plea for more Careful Preservation of all Biological Material from Prehistoric Sites" published in Southwestern Lore (1938).

8. As in so many disciplines, the major development in zooarchaeology came after World War II. It was not until then that professional zooarchaeologists became established in academic institutions and museums, and began to contribute consistently to the literature of the discipline. Most noteworthy during the early part of the post war period were the contributions of John E. Guilday at the Carnegie Museum of Natural History, Paul Parmalee at the University of Tennessee, and Stanley Olsen of the University of Arizona (see Bogan and Robison 1978 and Lyman 1979 for citations to their extensive contributions).

9. It was also the post war period that saw the clear definition of the aims and methods of zooarchaeology. Foremost among the postwar scholars who began to establish the methodology of zooarchaeology was Theodore E. White who in the early 1950s prepared a series of papers reporting his research into the butchering practices of prehistoric peoples of the American Southwest, and the techniques which he utilized to establish the relative number of individuals represented in a site and an animal's relative contribution of meat to the diet of the people of the site (White 1952, 1953a, 1953b, 1954, 1955, and 1956).

10. From the 1960s to the present the discipline of zooarchaeology seems to have grown at an exponential rate, as has all of archaeology. Part of the reason for this rapid growth in zooarchaeology was that by this time the second generation of zooarchaeologists, the first to have been specifically trained in the discipline, began to conduct research and publish their findings. Also, the increasing interest in zooarchaeology attracted scholars from other disciplines within anthropology and the biological sciences to devote more of their time to zooarchaeological research. It is impractical to review here the extensive literature that has been published within the past 20 years, rather those interested are referred to the bibliographic citations in Behrensmeyer (1975), Behrensmeyer and Hill (1981), Binford (1981), Bogan and Robison (1978),Gilbert (1980), Grayson (1984), Hesse and Wapnish (1985), Klein and Cruz-Uribe (1984), Lyman (1979), and Shipman (1981).

The Data Set of the Zooarchaeologist and the Questions Posed

11. It is useful to review here the nature of the faunal assemblage which zooarchaeologists examine, and the kinds of questions zooarchaeologists hope to answer from an examination of these remains. This familiarization with the materials and goals of zooarchaeology can give insight into what is considered essential to preserve.

12. Typically, the faunal assemblage recovered at sites consists of the hard parts of the skeleton and dentition of vertebrated animals and the shells of mollusks. In addition to these commonly preserved remains, softer tissue such as the hard parts of the exoskeleton of invertebrates (such as crabs, shrimps, and beetles), fish scales, bird feathers, muscle, skin, gut, and brains have been preserved. As examples, bison and mammoth fleshy remains have been found in permafrost and in anaerobic muds in Alaska as well as Eurasia (Sutcliffe 1985), brain and muscle tissue of humans have been found in peat in Florida (Doran et al. 1986), soft tissue of mummified animals found in dry caves have been reported in Texas (Steele et al. 1984), feathers have been recovered from archaeological sites in several regions of North America (Gilbert, Martin and Savage 1981), as has hair (Bonnichsen and Bolen 1985), fish scales (Casteel 1976) and insect remains (Gilbert and Bass 1967). Although not a body part of an animal, the faunal assemblage may also include scats of animals (Davis et al. 1984), and evidence of an indirect nature, such as footprints and chew marks.

13. The faunal assemblage at a site may consist of the body parts of a single animal or several animals of a single species, such as at a bison kill site. Or, the assemblage may consist of the remains of many specimens of many different species, as is typically seen in a faunal assemblage recovered from an archaeological habitation site. As examples of the nature of faunal assemblages recovered from habitation sites, Table 1 lists the number of genera of vertebrates recovered from a series of sites from southern Texas which the author has examined (Steele 1986a, 1986b, Hellier, Steele and Hunter n.d., Steele and Hunter 1986, Steele and Mokry 1985). Also listed is the number of bone fragments analyzed from each site. Note that many genera representing most classes of vertebrates are present, and that the animals represented range from some of the smallest extant vertebrates to the largest.

14. Each animal represented at a site will be represented by at least one bone fragment. In some instances the entire bone assemblage from a site may consist of a single articulated skeleton of an animal (Carlson, Steele and Comuzzie 1984, Steele and Carlson 1984), or a single shell. More typically, the assemblage will consist of several incomplete hard parts of one or more animals. As an example, Table 2 lists the skeletal elements

Table 1

Number of Elements and Genera Recovered from Late Holocene

Tamaulipan Faunal Assemblages

(after Hellier, Steele and Hunter n.d.).

	41JW8	41LK28	41LK201	41MC222	41MC296
Elements*	6,000	40,0001	3,500	6,000	9,000
Mammals	18	15	22	11	13
Reptiles	8	8	8	4	6
Amphibians	1	0	0	0	1
Aves	2	4	1	0	2
Osteicthyes	1	3	2	1	3
Total	30	30	33	16	25

*Number of bones recorded for each site are approximate
**Number of genera recorded for 41LK28 does not include the two genera of sharks recovered from the site.

Table 2

Number of Identified Elements per Taxa of Rodents

Recovered from 41 LK 28

ELEMENT	Spermophilus mexicanus No.	Geomys personatus No.	Geomys sp. No.	Perognathus sp. No.	Neotoma sp. No.	Sigmodon hispidus No.	Liomys irroratus No.
Skull	18	-	1	1	-	-	-
Maxilla	-	-	-	-	1	-	-
Mandible	3	-	1	1	2	4	1
Tooth	1	1	1	1	2	-	-
Vertebrate indet.	40	-	-	-	-	-	-
Rib	40	-	-	-	-	-	-
Scapula	2	-	-	-	-	-	-
Humerus	2	1	1	-	-	1	-
Radius	1	-	-	-	-	-	-
Ulna	1	1	-	-	-	-	-
Pelvis	4	-	-	-	-	-	-
Femur	2	-	3	-	-	3	1
Tibia	2	-	-	-	-	1	-
Fibula	1	-	-	-	-	-	-
Phalange, prox.	6	-	-	-	-	-	-
Phalange, distal	6	-	-	-	-	-	-
Phalange, intermed	2	-	-	-	-	-	-

representing genera of rodents recovered from a site in southern Texas, 41 LK 28 (Hellier, Steele and Hunter n.d.). In this example, as is typical at other sites, a complete skeleton is not represented in the site, nor are all skeletal elements equally represented in equal number.

15. Just as animals in faunal assemblages are rarely represented by complete skeletons, each body hard part is typically broken and incomplete. While I have no tabulation of the number of complete versus incomplete skeletal elements recovered from faunal assemblages, it is my estimate that less than 1.0% of the faunal assemblages of the six sites which are reported in Table 1 are complete bones. Those few bones which do survive intact are the hard, compact bones of the wrist and ankle of vertebrates, and the vertebrae and long bones of small mammals. The other skeletal elements are typically fragmented by a myriad of forces which reduce the bones from the time the animal dies until the time when the element is recovered by the archaeologist.

16. Focusing upon just what animal remains are present in the faunal assemblage, however, fails to identify the complete data set zooarchaeologists use to answer the questions they ask about human behavior, ecology and evolution.

17. To illustrate the point, imagine a successful hunting party returning to a habitation camp with a deer. Some member of the camp will butcher the deer, and in the process he or she accidentally will leave tell tale scratches upon the bone indicating how the animal was butchered. Then, the carcass more than likely will be distributed around the site as the fruits of the hunt are shared with other camp members. Individual bones may be saved to be made into tools, and finally, the long bones may be broken to extract the marrow and the cortical chips of bone boiled to extract the grease. A zooarchaeologist, then, hoping to reconstruct this sequence of events would need to know more than which animal was killed and what parts brought back to the camp. He also would need to know how the remains were modified at each process, and where these activities occurred. Thus, the condition and the context of the bone within the site is as important to the zooarchaeologist as which bones and species are represented.

18. Given the data set which zooarchaeologists examine, many of the questions zooarchaeologists seek to answer may be self evident. Certainly, one of the most paramount series of questions asked concern the role animals may have played in human diets. These are questions, such as, what animals were harvested? Were they hunted, or gathered as slow game (Coon 1971)? Were they killed singly, or in mass? Were they speared, netted, trapped, poisoned? When were they hunted, and where? Did human hunters harvest all habitats equally, or did they preferentially harvest select areas within the environment? Did they hunt the same animals fall, winter and spring, and in the same

fashion? Did they hunt day, twilight, or night? The questions concerning when humans hunted are also of interest to all archaeologists for the answers to these questions also provide some of the best clues concerning when the site was occupied, and for how long.

19. Another set of questions involves the sorts of social and cultural behavior associated with the processing of these animals and their utilization. Once the game is collected, the remains usually are prepared in some fashion and commonly shared, as the imagined sequence outlined above indicates. Realizing this has led zooarchaeologists to ask questions about butchering practices, food processing habits and patterns of food distribution. Zooarchaeologists also are interested in how animal remains are utilized other than for food. This raises questions as to which animal parts were used for tools and ornaments, and how they were fashioned.

20. One area of particular interest to zooarchaeologists concerns domesticated animals. The domestication of plants and animals represented one of the most significant steps in human evolution, for the domestication of plants and animals often provided a more constant and larger source of food. The domestication of animals also provided a source of energy to humans other than their own. Because of the importance of this historical event many zooarchaeologists have devoted their professional lives to questions surrounding domestication.

21. Commonly, in North American zooarchaeology we do not place much emphasis on this issue, yet domesticated animals were a part of the North American human ecosystem. Throughout North America, there is prehistoric evidence of the dog. Later in historic times the horse became of immense importance to many groups of North American Indians. In the American Southwest the turkey was kept, either as a domesticated animal, or a penned wild animal. For North American zooarchaeologists interested in domestication in prehistory, their interests revolve around documentation of the presence and importance of the dog, and the utilization of exotic species such as parrots and turkeys. At historic sites of peoples of European extraction, however, the typical questions concern the relative importance of wild game versus domesticates, which domesticates were present, and how were they utilized.

22. To fully understand the range of human behaviors which occurred at a site, and the adaptations which the humans made to living in the region inhabited, it is necessary to reconstruct the environment within which they lived. One of the major sources of information about these past environments are the remains of the animals which lived within them. Zooarchaeologists then, often attempt to reconstruct paleoenvironments by reconstructing the animal community of the times. The best sources for these remains are the animals recovered from archaeological sites.

23. Finally, zooarchaeologists are interested in the biology of the animals themselves. What did the animals look like? What was the status of their health? To understand the natural history of the Holocene vertebrates paleontologists must rely upon the archaeological record for this is the single richest source available for Holocene vertebrates.

24. From this short review it becomes apparent that the zooarchaeologist is interested in all the animal remains within the site, not just the most complete, or the rarest. To the zooarchaeologist, the bits and pieces broken by humans provide information about human behavior as much as the complete elements provide. And, it is apparent that where the animal remains are found within the site, the context is as important as the remains themselves.

Zooarchaeology and the Subdiscipline of Taphonomy

25. To best reconstruct the features of a prehistoric animal, the remains should be as complete as possible. However, this is rarely the case. Soft tissue is a rarity in the prehistoric record, complete skeletons are uncommon, and in fact, the common condition is for bones to be broken, marred and incomplete. Similarly, to reconstruct the human behavior which occurred at a site, all bones brought to, altered, and scattered about the site should be preserved in their pristine condition and context. Again, this condition rarely, if ever, has been found. To reconstruct the prehistoric animal, and to reconstruct the prehistoric human behavior at a site zooarchaeologists must be able to differentiate alterations to the individual bone elements, and to the bone assemblage, made by humans at the time of their activity, and alterations made by other agents at a later date.

26. The subdiscipline within zooarchaeology which develops the methods to differentiate human forms of alteration from nonhuman forms of post mortem alteration to bone is taphonomy, a subdiscipline shared with all paleontological sciences (Behrensmeyer 1975, Beherensmeyer and Hill 1980, Binford 1981, Brain 1981, Shipman 1984). Taphonomy is founded on two basic observations. First, animal remains are degradable. They can be reduced in mass, structure and composition by mechanical, chemical and biological means. Second, the degradation commences when the animal dies and continues until its remains are recovered.

27. Taphonomists interested in the processes of the degradation of faunal remains in nature recognize five stages in the transformation of a living community of animals to the point when a few remnant pieces of a few individuals are recovered (Clark and Kietzke 1967, Meadow 1980, Klein and Cruz-Uribe 1984). These are:

a. Life Assemblage (the animal community existing in the region in their natural proportions).

b. Death Assemblage (the carcasses, or portions of carcasses collected by humans, carnivores, or other bone accumulating agents).

c. Deposited Assemblage (the carcasses or portions of carcasses that come to rest at the site).

d. Fossil Assemblage (the parts that survive in a site until excavation or collection).

e. Sample Assemblage (the part of the fossil assemblage that is excavated or collected).

28. Zooarchaeologists are interested in reconstructing the life assemblage and understanding the human contribution to creating and altering the death assemblage and deposited assemblage. However, at each of Stage 2 - 4, faunal material can be added, deleted or reduced in some fashion by bone reducing agents other than humans. Consequently, zooarchaeologists to date have concentrated upon recognizing distinctly human patterns of bone modification and destruction, and distinguishing these from non human patterns of bone accumulation and modification during Stages 2 and 3 (Behrensmeyer 1975, Binford 1981, Brain 1981, Bonnichsen 1979, Carlson, Steele and Comuzzie 1984, Haynes 1980, 1983, Morlan 1980, Shipman 1981, Steele and Carlson 1984).

29. The issue which will be explored further here, however, is what happens to animal remains during Stage 4 when they are a part of the fossil assemblage. Specifically, the concern is to identify what forces continue to reduce and disperse the bone assemblage, thus reducing its quality as an archaeological site. This information in turn will hopefully permit us to predict the potential effect of inundation or burial of a site.

Alteration of Animal Remains During the Processes of Fossilization

30. Zooarchaeologists have determined that animal remains, once buried, can continue to be moved, reduced by mechanical and biological means, distorted, chemically altered, chemically eroded, impregnated and mineralized.

31. Once an animal dies the biological decomposing agents such as fungi, microbes and bacteria begin to reduce the organic material to its constituent elements. This process continues after the material is buried. In fact, the entire decaying process can occur in the burial environment if the body is buried immediately. This decay process is accelerated if

sufficient amounts of oxygen and an acceptable aqueous environment occurs in the soil to support the decomposers.

32. Nor does the process stop once the flesh is gone and only the bones remain, for as much as 20.0% to 25.0% of dry bone weight is organic material, primarily collagen. In general, three things occur to the bone collagen through time in a site. The first is that it is gradually destroyed through time so that typically, newer bone has more collagen than older bone. Second, the frequency of surviving amino acids will typically be different from the frequencies found in fresh collagen. This may be because some amino acids are more resistant to decay than others, or non collagen proteins survive better and are differentially contributing to the amino acids recovered. Third, those amino acids which survive will be represented by a greater number of D-amino acid isomeric forms, rather than the L-aminoacid isomeric forms which are typical of fresh collagen (Hare 1980). Table 3 documents the alterations in the amino acids of recent bone and selected examples of fossil bone.

33. In addition to the loss of the collagen matrix the mineral portion can be lost as well. The inorganic constituents of bones are primarily calcium salts and are subject to dissolution in acidic conditions. These conditions are typically created by ground water. Dental remains alone have been recovered in situ from a burial at 41 BU 16. Their placement within the soil matrix documents that the teeth are still in anatomical position to one another. The bone surrounding the teeth, however, has been dissolved by the acidic conditions of the soil and groundwater to the point that none of the bone remains. Bone preservation at this site also illustrated the apparent micro differences in soil chemistry within the site, for bone was preserved within 1.0 m of this individual. Roots also create an acidic environment immediately around the root, and roots coming in contact with bone will commonly etch it.

34. During the Fossil Assemblage (Stage 4) movement can be a major degrading force. Movement of materials at a site can occur by geological processes, such as slumping, or by biological means. In fact, the extent of this turbation can be so great that virtually all primary horizontal and vertical provenience is destroyed. On relatively level sites, bioturbation is the most significant factor moving materials within the site. One of the major botanical causes for movement of materials is the uprooting and toppling of a tree. When this occurs, soil may be disturbed several feet beneath the surface.

35. Animal disturbance is another major biological factor moving materials within a site. Small invertebrates, such as earthworms and ants, are known to effectively move soil, but their contributing effect to movement of materials within an archaeological site has not been documented. Larger vertebrated animals also move material within a site and their

Table 3

Amino Acid Composition of Selected Fossil Bones

Compared to Modern Bone

(after Hare 1980)

	Modern bone	*(A) 2,000yr	(B) 4,000yr	(C) 4,990yr	(D) 6,000yr	(E) 80,000yr
Amino acid						
OH-Pro	100	99	63	-	90	97
Aspartic	50	34	160	230	66	48
Threonine	19	3	3	19	16	22
Serine	35	11	8	23	32	37
Glutamic	78	84	180	224	82	73
Proline	109	114	80	25	110	124
Glycine	330	362	288	200	334	340
Alanine	112	134	110	78	117	111
Valine	21	26	20	47	21	18
Methionine	4	0.2	4	8	6	4
Isoleucine	11	10	9	19	8	10
Leucine	28	29	25	38	23	23
Tyrosine	4	-	-	-	-	2
Phenylalanine	14	-	-	-	20	12
Histidine	4	-	-	-	2	2
OH-Lys	4	-	-	-	2	2
Lysine	25	41	22	33	34	28
Arginine	53	53	28	36	40	48
Nanomoles/mg of amino acids	2500	2300	140	2.3	200	1250
Ratio of D/L Isomers of Aspartic Acid	0.05	0.56	0.25	0.40	0.22	0.20

*(A) from 25th Egyptian Dynasty
(B) from 12th Egyptian Dynasty
(C) from California specimen dated by C14
(D) San Diego specimen dated approximately 6,000 years
(E) Maryland Pleistocene specimen dated approximately 80,000 years

effect on archaeological sites has been evaluated (Chew 1978, Wood and Johnson 1978, Erlandson 1984, Bocek 1986, Hunter n.d.). Based upon Chew (1978) and Golley, Ryszkowski and Sokur (1975), Bocek (1986) stated that a reasonable range for annual rodent displacement of earth is 3 to 15 cubic meters per hectare. Wood and Johnson (1978) estimated that gophers may move as much as 15.0% to 20.0% of the surface soil in one season, thus causing complete mixing of the soils within five or six years. Bocek (1986) felt that most of this turnover of soil will occur within the top 30.0 cm of the site.

36. While rodents can move a significant amount of earth there appears to be limits to the size of the particles which can be moved within the tunnel. Hansen and Morris (1968) documented that particles 0.6 cm to 2.5 cm occurred more frequently in gopher backdirt that in the surrounding matrix, and Dalquist and Scheffer (1942) and Murray (1967) noted that maximum particle size moved by gophers directly appeared to be 5.0 cm. Bocek (1986) noted, however, that larger particles could be displaced downwards by the earth being moved from beneath it.

37. While Hunter (n.d.) generally confirmed these effects gophers had on a similar site (41 Bu 76), she documented gopher burrows extending deeper than Bocek saw at a site in California. Hunter noted gopher burrows as deep as 90.0 cm into the site. She further documented that 44.0% of the gopher bones recovered at this site were 60.0 cm from the surface.

38. In addition to gophers, other vertebrates are known to burrow within a site. Badgers, canids, armadillos, and gopher turtles are common burrowers, and humans are as well. At a large cemetery humans may bury as many as 100 individuals, and in the process be a major disruptive force to previous occupation horizons within the site.

39. Bone breakage also continues to occur during the fossilization process. Bone within a site can be broken both by mechanical as well as biological means. The weight of overburden can crush poorly supported bone within a site, and compressive forces at a site can exacerbate the breakage. A human skull recovered from the sandy soils of 41 BU 16 was crunched to the point where none of the original bones remained intact and the skull which was laying on its side occupied less than 50% of its original space (Steele n.d.). Both plants and animals can also break bone. Roots of large shrubs and trees penetrating the soil of a site are known to physically break bone which they encounter, and animals gnawing on bone encountered while burrowing through the site reduce the bone assemblage. At 41 LK 28 Hellier, Steele and Hunter (n.d.) reported that approximately 2400 elements, 06.0% of all bone recovered, exhibited evidence of gnawing.

40. Distortion of bone remains is a form of degradation which occurs primarily during the process of fossilization. Shipman (1981) recently reviewed forms of deformation

occurring during fossilization and differentiated between plastic and mechanical deformation. The former occurred when bone was subjected to uniform stresses and the bone material was stretched or compressed, but not broken. Mechanical deformation occurred when the bone was broken, and matrix filled the cracks, spreading the bone. Because of the recency of the archaeological record within the Americas, few if any examples of plastic distortion have been reported here.

41. Finally, animal remains can become impregnated and mineralized during the stage of the Fossil Assemblage. Permineralization occurs when waterborne minerals impregnate the bone and fill the voids left by the decay of organic materials. Mineralization is the process of replacement of the mineral salts (Shipman 1981). While permineralization and mineralization are not processes which have occurred at most American archaeological sites, it has occurred in some of the Late Pleistocene and Early Holocene human sites (Wendorf et al. 1955, Young 1986).

Model of Bone Degradation at a Buried Site

42. Considering the various forces which continue to alter the bone assemblage during the period when the site is buried, several factors can be proposed which will enhance the state of preservation at a site. The first of these is the reduction or removal of biological organisms from the buried site. Biological organisms were identified as the primary decomposers of proteinaceous material, major forces moving bone within a site, and one force (but probably not a major force) breaking and reducing bone within the site. At sites which are too cold (such as in permafrost), too dry (such as in deserts), anaerobic (such as in some bogs and muddy sites) or too dark (such as in deep caves) organic material will be well preserved.

43. The inorganic matrix of bone can be preserved at sites where acid content is low because the matrix of bone is principally composed of calcium phosphates. These are usually limey soils, or soils low in acid water content.

44. Bone is also better preserved at sites where the soil is not subject to alternative wetting and drying, or thawing and freezing. In both of these alternating conditions the changes in water content in and surrounding the bone creates differential pressures which crack or break it. The effects of alternating wetting and drying (or freezing and thawing) can be so dramatic as to reduce a long bone from a mammoth to bone fragments no bigger than chips the size of a fingernail.

45. Bone assemblages can be better preserved where the bone is not subject to uneven compressive forces. These are sites which are buried under an overburden thick

enough to protect the bones from crushing caused by vehicular traffic, but shallow enough not to be subject to the compressive force of the overburden itself. These sites are also usually sites with a soil matrix which evenly supports the bony pieces.

46. Finally, bone assemblages can be better preserved on relatively level surfaces where they are not subject to slumping or reexcavation by water runoff.

47. While these factors clearly indicate that certain conditions can enhance preservation at a site, and others can accelerate the destruction of the bone assemblage, it is also clear that in a buried site the bone assemblage and all the forces which affect its preservation are in dynamic interrelationships. Consequently, alleviating one negative force impacting bone in the burial environment may not produce the positive conditions for preservation. Alleviating that one force may in fact create a greater negative impact elsewhere.

48. Because this dynamic nature of the bone assemblage in a burial site has not been carefully studied I would propose a series of experimental tests be conducted to evaluate the efficacy of site burial as a means of preserving or stabilizing archaeological sites. These tests should be extensive in nature, undertaken within a variety of geographical locales, and be monitored over significant lengths of time. Such tests have not been conducted successfully as yet, and without them we cannot accurately predict the value of protecting the bone within sites by burying the site.

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BOTANICAL REMAINS IN ARCHAEOLOGICAL SITES

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Introduction

1. One of the primary objectives in the field of archaeology is to construct and explain, as accurately as possible, the material culture and subsistence patterns of past cultures (Deetz 1967). When examining one aspect of this, the botanical record, the archaeologist must rely upon a wide range of information which may lie on the surface or buried within the sediments of a site. These remains include a wide range of macrofossils, microfossils, and non-botanical items which reflect the use of plant materials. For example, many sites will contain specific artifacts which indicate some aspect of the food economy such as lithic and bone knives used for cutting plant materials, stone slabs used for grinding seeds, bedrock motars used for breaking open nuts and seeds, wooden clubs used to beat seeds from their stalks, digging sticks used to recover roots and tubers, baskets used for gathering and storing plant foods, and ceramics used for seed storage or cooking. Other more direct clues about past subsistence patterns can be reconstructed from archaeological sites through a careful collection and analysis of preserved botanical macrofossils such as seeds, leaves, bark, flowers, wood, or charcoal and preserved microfossils such as pollen, phytoliths, or diatoms. Even chemical traces left in the soil as indicated by the pH, Eh, or trace element tests may offer indications of past plant use.

2. Even though the above forms of evidence are useful, the most accurate method for interpreting the diet patterns of a past culture is derived from human coprolites (preserved feces). Coprolites are useful since they represent the undigested plant remains which passed through a human digestive system. As such, they reflect, as precisely as possible, what foods were eaten, how nutritious those foods were, and how the food products were prepared (cooked, eaten raw, or ground).

3. Once botanical data are collected from sites and analyses are completed, the archaeologist is provided with an opportunity to use these data to speculate about a variety of aspects. These include the paleoenvironmental record, diet and subsistence patterns, human nutrition and disease, the level of prehistoric technology, and in some cases even the direction and distances of possible trade routes. As ideal as this sounds, the practical opportunities for these types of reconstructions are often limited by a variety of factors over

which the archaeologist has little control. These factors include: 1) whether or not artifacts made from plant materials were lost or discarded in the areas of a site that are later excavated, 2) whether or not plant debris from foods were discarded as refuse at a site, 3) whether or not the plant debris at a site has been destroyed by a variety of weathering agents, and 4) whether or not excavation techniques were utilized which specifically searched for all aspects of the potential botanical record.

Paleoethnobotany

4. Today, the specific discipline which trains specialists to investigate and analyze the botanical record from archaeological sites is called either archaeobotany or paleoethnobotany. Initially, an American named John Harshberger was searching for a word to represent his study of dried plant remains recovered from pueblo sites in the American Southwest. His new term for this study was ethnobotany, which he defined as the study of plants used by primitive and aboriginal peoples (Harshberger 1896). This term remained in general use to describe the study of plant remains found in archaeological sites until the late 1950's when Hans Helbaek introduced the term paleo-ethnobotany. Helbaek (1959) used this new term to reflect the research being done on how ancient cultures used plants, especially in regards to the study of early plant domestication. Even so, the term "ethnobotany" was still preferred by some authors, such as Towle (1961), to represent the study of ancient plant usage by mankind. Later, Jane Renfrew used the term "paleoethnobotany" as the title of a book and redefined the term as, "the study of the remains of plants cultivated or utilized by man in ancient times, which have survived in archaeological contexts" (Renfrew 1973).

5. In 1979, still another term, "archaeobotany", was introduced by Ford to refer specifically to, "the recovery and identification of plants by specialists regardless of discipline" (Ford 1979). Ford introduced the new term since the older term, paleoethnobotany, implied both identification and subsequent interpretation. On the other hand, archaeobotany suggests only the techniques of recovery and identification.

Developmental History

Plant macrofossils

6. In most fields it often takes something of a unique or spectacular nature to catch the eye of professionals and create a widespread interest. So it was with the recovery and analysis of plant remains from archaeological sites. Although earlier archaeologists undoubtedly found and noted the presence of botanical materials, it was Kunth's (1826) analysis of dried fruits, grains, and seeds found in the tombs of ancient Egypt that caught

the interest and imagination of the archaeologists of that day. Later, Heer's (1865) equally important report of preserved plant materials found in the waterlogged sites of ancient Swiss lake dwellers demonstrated that plant materials could be recovered and analyzed from sites in areas other than the desert. Following these two important early studies a few other archaeologists began having plant materials identified and listed in appendices of their reports. A brief summary of some of the other early studies of plant remains from archaeological sites during the middle and late 1800's is noted by Renfrew (1973).

7. In the Western Hemisphere the field of paleoethnobotany began when a French botanist named Saffray (1876) identified the plant materials recovered with a mummy found in a dry cave site in Peru. Meanwhile, in the nearby Ancon region of Peru individuals such as de Rochebrune (1879) described the plant remains from cemetery sites and later Wittmack (1880-1887) elaborated on those materials and other plant remains found in Peruvian archaeological sites. In spite of these excellent studies in South America, early archaeological concerns in North America focused chiefly on ways to topologically and chronologically order the material remains of past cultural groups (Jones 1957).

8. From the beginnings of North American archaeology through the end of the late 1920's almost no interest was given to the recovery or analysis of plant materials from archaeological excavations. As noted by Jones (1957), the primary reasons for this disinterest were the perishability and intermittent occurrence of plant remains at sites, excavation and recovery techniques not designed to maximize the recovery of plant remains, and the difficulty of finding a botanist who was willing to identify plant remains once they were found. In the 1930's this attitude towards the paleoethnobotanical record changed quickly. On September 17, 1930, Dr. Carl Guthe sent a circular to most of the active archaeologists of that day saying that a botanist, Dr. Gilmore of the Museum of Anthropology at the University of Michigan, would act as a clearing house for the collection and identification of botanical remains from archaeological sites. In addition, in order to get a prompt response, Dr. Guthe indicated that this service would be provided free of charge (Jones 1957). In a subsequent circular written by Dr. Gilmore (1932), he outlined the importance of ethnobotany and explained the organization and services provided by the newly created Ethnobotanical Laboratory of the University of Michigan. Gilmore's initial explanation was later expanded and detailed by the laboratory's next director, Volney Jones (1941).

9. To say that Dr. Guthe's initial invitation was a success is understating the situation. During the next two decades the newly created Ethnobotanical Laboratory received more than 4,700 groups of samples from 390 different sites. The total specimens in these samples numbered in the thousands (Jones 1957). During his career as head of the

Ethnobotanical Laboratory, Jones established many of the early standards used by the discipline. More importantly, he trained a new generation of ethnobotanists who for the first time combined academic and research training from both the fields of archaeology and botany. These graduates went on to establish research laboratories and academic training centers of their own and began training the third generation of ethnobotanists. Recent summaries of the history of paleoethnobotany in North America (Ford 1978, 1979, and 1985, Bohrer 1986) point out how the discipline has expanded and changed in focus since the early 1930's and describe the steps which still need to be taken to improve this field of study.

Plant microfossils

10. Up until this point I have been addressing the history and development of paleoethnobotany as it pertains to the study of plant macrofossils, those larger portions of plants which are easily seen with the naked eye or with a hand lens. Of equal importance is the developmental history of two other specialized areas of paleoethnobotany: palynology (fossil pollen analysis) and the relatively new science of phytolith (plant crystals) studies. These and other types of small plant remains, such as diatoms, are often referred to as plant microfossils.

11. The validity of applying fossil pollen analyses to solve problems in archaeology is based upon six major premises. First, many of the plants used by cultural groups contain pollen either in the form of flowers, or inadvertent pollen which has been dispersed but remains clinging to non-floral parts of the plant such as the leaves, stems, fruits, or seeds. During man's use of these plant parts some of the flowers and pollen are often released and become incorporated into the soils of a site. Later, these released pollen grains can be recovered and used to identify the types of plants that produced them. Second, most pollen grains produced by terrestrial plants have a chemically stable outer wall, called an exine, which is highly resistant to deterioration and is fairly easy to extract from the sediments of archaeological sites. Third, pollen grain wall morphology is consistent within a given species and is generally different among unrelated plant taxa thereby permitting the pollen of one genus or species to be recognized from types produced by other plants. Fourth, many plants produce great quantities of pollen which are dispersed and eventually fall to the ground in a predictable pattern called the pollen rain. This pollen rain often falls onto the occupational surfaces of sites being used by man and forms a fairly accurate record of the local wind pollinated vegetation within a radius of approximately 45 km. Fifth, since pollen grains are organic and are very resistant to decay, they can be used as a scale to measure the severity of organic plant decomposition in archaeological sites. And sixth, in cases of severe organic decay in the sediments of archaeological sites, pollen grains, and/or

plant phytoliths, may remain as the only clues of plant usage by cultural groups.

12. Like pollen studies, phytolith analyses have become recognized as a useful tool in the field of archaeology for a number of reasons. These include: 1) since these plant remains are inorganic, they are not subject to the same kinds of decay and oxidation processes common to other botanical remains such as pollen, leaves, wood, and seeds; 2) phytoliths are relatively easy to recover from sediments; and 3) certain phytoliths contain morphological features which permit them to be identified as coming from distinct plant species. For these reasons phytoliths often can be recovered and identified from the soils of archaeological sites when all other traces of plant materials have disappeared (Rovner 1971, 1983).

13. Phytoliths are ideal for paleoethnobotanical studies because they are found in a wide range of plants and are inorganic. Phytoliths are formed from anhydrides of silica and calcium oxalate which plants absorb, but cannot excrete, thus the plants must deposit these compounds in special cellular spaces located in the epidermal tissue of stems, leaves, and sometimes roots (Esau 1965). Phytoliths come in a wide variety of sizes and shapes, and like pollen, many forms are specific only to one genus or species of plant (Baker 1959b).

14. Use of fossil pollen data to resolve problems in archaeology prior to the 1940's was rare and even when attempted it was generally used only to establish relative chronologies within sites. There were a few attempts to broaden the use of fossil pollen data from archaeological sites, yet it wasn't until the early 1940's that new and dramatic archaeological applications of palynological data were first demonstrated by Iversen (1941). In his study Iversen successfully identified the beginning of the Neolithic period in Denmark by correlating it to other specific events. These included: 1) the decline of elm pollen caused by the cutting down of local elm forests, 2) the first appearance of domesticated cereal pollen from plants not native to Denmark, and 3) a sharp rise in pollen from herbs and weedy plants normally associated with human disturbance and occupation. Thus, Iversen's study realized three important goals: 1) it defined the precise arrival date for the introduction of agriculture into northern Europe, 2) it provided new information about the types of domestic plant species introduced into northern Europe by peoples migrating up from the south, and 3) it explained how prehistoric cultures altered the equilibrium of the natural vegetation by clearing the forested areas for farmlands using slash and burn techniques.

15. As with the study of plant macrofossil remains, Europeans were the first to take the initiative in the use of fossil pollen from archaeological sites. In North America, the application of palynology to the field of archaeology came later and grew more slowly than it did in Europe. In an article published in American Anthropologist, Sears (1932) was the

first to use fossil pollen data to correlate a direct relationship between a climatic shift (which favored the growth of maize) and the simultaneous expansion of Hopewell cultures into many new areas of eastern North America. Sears (1937) later went on to pioneer fossil pollen investigations of sediments in the American Southwest where many of the early archaeological studies in North America were being conducted. However, Sears' initial attempts in the Southwest resulted in only limited success. Although others, like Anderson (1955) were the first to extract and study fossil pollen from archaeological sediments in Southwestern caves, it wasn't until the early 1960's that Paul S. Martin (1963) and his students began a systematic study of fossil pollen from Southwestern sites.

16. Between the early 1960's and late 1970's more and more attention was given to the sampling of archaeological sites for fossil pollen. Nevertheless, four main factors prevented this technique from becoming commonplace. First, the number of trained palynologists in North America who had an understanding of archaeology and/or were willing to examine archaeological pollen samples was limited. Second, widespread use or interest in fossil pollen studies did not become popular during this period because of negative results produced by a number of studies that were conducted in areas where pollen preservation was marginal or non-existent. Third, existing pollen extraction and analytical techniques had been developed and perfected primarily for use in bog sediments where organic preservation is ideal and the primary analytical objective is vegetational reconstruction. Adequate extraction and interpretive techniques for use on archaeological sediments were still in the developmental stage. And fourth, conducting fossil pollen studies were not yet required as part of the scope of work by most contract-type archaeological projects. This last aspect was important since a majority of the archaeological excavations at that time were funded by government agencies such as the National Park Service, United States Forest Service, Corps of Engineers, Soil Conservation Service, and the Department of Defense.

17. By the mid to late 1970's macrofossil paleoethnobotanical studies and fossil pollen analyses became routine aspects of most archaeological studies. In some cases only limited testing for the presence/absence of plant macrofossils and fossil pollen was required as part of the scope of work. In other cases, the search for these botanical remains became an important part of the original planning and excavation of sites. Later, these data were incorporated into many of the site reports and formed major parts of the analysis and interpretation sections. Several recent articles have focused on the historical development and later scope of fossil pollen studies in archaeology. These include articles by King (1975), Bryant and Holloway (1983), Dimbleby (1985), and Holloway and Bryant

(1986).

18. A subfield of paleoethnobotany which is still in its infancy is the recovery, study, and analysis of phytoliths recovered from archaeological sites (Rovner 1983). Schellenberg (1908) was the first to note the presence of phytoliths in the soils of archaeological sites during his study of plant remains from North Kurgan, USSR. However, other scientists did not attempt to utilize this source of information until fairly recently.

19. Beginning in the late 1950's Helbaek (1959, 1961, 1963) reported the recovery of phytoliths from a number of archaeological sites in the Middle East. He noted the presence of phytoliths from wheat, oats, millet, and rice in such diverse deposits as crushed Neolithic shards, ash layers, and midden deposits. At the same time researchers such as Beavers and Stephen (1958) and Baker (1959a) were recovering and examining phytoliths from grassland soils with the hopes of using those data as indicators of past vegetation assemblages.

20. More recently, authors like Pearsall (1982) and Piperno (1984) have shown that phytoliths in soils can be used successfully to document the presence and use of domestic plants, such as maize, even when other traces of botanical evidence are absent. They also noted that phytolith studies are especially useful in areas, such as the tropics, where soil oxidation of most plant material is rapid and complete.

21. Although fairly uncommon at most archaeological sites, diatoms can be recovered from the sediments of some sites and utilized as an indicator of nearby water sources or local environmental conditions (Williams-Dean 1978). This is true since certain diatom genera thrive only in wet environments within specific limits of temperature and salinity (Smith 1955).

22. Diatoms are microscopic forms of algae which produce outer shells of inorganic silica and thus remain preserved in sites where decay processes destroy organic plant remains. Although diatoms do not represent a known food source normally sought by cultural groups, diatoms may be inadvertently collected in drinking water or soils adhering to the roots of plants used for food. As such, these diatoms can be ingested or incorporated into the soils at archaeological sites.

Human coprolites

23. Like the study of plant macrofossils, the recovery and analysis of human coprolite remains from archaeological sites have a long history. On the other hand, the subdiscipline of coprolite studies did not receive adequate attention or emphasis in the field of archaeology until only recently (Bryant 1974c).

24. In his now famous article, Harshberger (1896) not only introduced the new term ethnobotany, but also became the first person to emphasize the potential value of human

coprolite analyses. A few years later, Young (1910) examined some dried human coprolites from Salts and Mammoth caves in Kentucky and concluded from his analysis that prehistoric peoples in that region ate sunflower seeds and hickory nuts as food.

25. During the next half century there were only a few additional coprolite studies. Loud and Harrington (1929) looked at several coprolites from Lovelock Cave, Nevada and noted that they indicated early Archaic cultures in that region ate a variety of wild plants and seeds. Volney Jones (1936) broke open some coprolites found at Newt Kash Hollow Shelter in Kentucky and found they contained a mixture of ground seeds from canary grass, pigweed, and sunflower as well as the remains of acorns and hickory nuts. Sperry and Fonner found a mixture of mesquite seeds, antelope hair, and bird feathers in prehistoric human coprolites from Danger Cave, Utah (Jennings 1957). And MacNeish (1958) noted that human coprolites recovered from archaeological sites in Tamaulipas, Mexico contained maguey fibers, squash seeds, insect fragments, and pieces of snail shells.

26. Callen and Cameron (1960) marked the beginning of a new era in coprolite analysis with their report of human coprolite remains recovered from Huaca Prieta, Peru. Callen later went on to become the first scientist to devote his full research efforts to the study of human coprolites. In rapid order he published a number of major coprolite studies on material from the Ocampo caves of Tamaulipas, Mexico (Callen 1963); Peruvian archeological sites (Callen 1965); and the analysis of over 100 human coprolites from Tehuacan, Mexico (Callen 1967) before his untimely death in 1970.

27. Using the new analytical techniques perfected by Callen, other researchers began examining human coprolites. During the late 1960's a large number of coprolite reports resulted from studies conducted in the arid west (Heizer 1960, 1967, 1969, Ambro 1967, Cowan 1967, Roust 1967, Tubbs and Berger 1967, Callen and Martin 1969, Fry 1969, Heizer and Napton 1969, Napton and Kelso 1969). At the same time, coprolites also were being recovered and analyzed from sites in the southwestern and eastern parts of North America (Martin and Sharrock 1964, Bryant 1969, Yarnell 1969, Riskind 1970, Bryant 1974a, 1974b, Schoenwetter 1974, Bryant and Williams-Dean 1975). More extensive treatments of the history and development of coprolite studies in archaeology can be found in articles by Bryant (1974c), and Fry (1985).

Data Base

28. The potential botanical record for any archaeological site can be examined from three different perspectives: a Primary Data Base, a Secondary Data Base, and a Tertiary Data Base. The Primary Data Base (PDB) consists of all the plant materials used by a

given culture, at a specific location, during a specified unit of time. This unit of time could be a few hours or could be thousands of years depending on how a researcher wishes to define it. As one might imagine, the entire Primary Data Base at an archaeological site is very rarely recovered.

29. Under special circumstances, the Primary Data Base becomes the Secondary Data Base (SDB). However, more frequently this does not occur because the SDB is defined as the preserved portion of the PDB. Finally, the Tertiary Data Base (TDB) represents a specific portion of the SDB which is actually recovered and analyzed from a given site. Thus, it would be possible to create one, or a series of TDBs, for a site depending on how the botanical remains for a site are recovered and analyzed. For example, for any small area within an archaeological site, or for the site as a whole, it would be possible to divide the recovered botanical remains into individual TDBs (pollen, plant macrofossils, coprolites, and phytoliths) or combine all of the analyses into one large TDB.

30. Terms similar in concept to PDB, SDB, and TDB already exist in the published literature (Birks and Birks 1980) but apply more directly to ecological situations and are not exactly parallel to the concepts I have presented above. For example, biocoenose is defined as the "life assemblage at a given location" and thanatocoenose is defined as the "death assemblage at a given location." The process of decomposition and/or preservation is referred to as the period of fossilization and the recoverable materials at a given location is referred to as the fossil assemblage.

Primary Data Base

31. From the beginning of mankind plants have been an important and critical aspect of human existence. For any site, the ways in which mankind uses plants, and all of the specific plants that are used form the basis for the PDB. The many uses of plants and the names of all the known plants used by mankind are beyond the scope of this article. Instead, a few examples will provide a general idea of what types of information form a PDB.

32. Mankind's most important use of plants is for food. Throughout the world in the past and today cultural groups make use of a wide variety of plant foods derived from leaves, tubers, roots and bulbs, seeds, stems, fruits, nuts, corns, bark, flowers, pollen, and nectar. These foods are prepared in a wide variety of ways including pounding, grinding, boiling, soaking, steaming, charring, and finally chewing. Some of these preparation processes (grinding and pounding) leave traces which often can be recovered from the sediments of sites. Other processes, such as chewing, will leave traces of the undigested food products in coprolites or on plant remains in the sediments. For example, at Hinds

Cave we found thousands of chewed sotol and agave quids (Shafer and Bryant 1977). In a few cases the impression of tooth marks were still clearly visible on the quids. Still other processes such as boiling leaves, flowers, or stems as teas or for medicinal purposes may leave only pollen or phytolith traces, or no traces at all.

33. Throughout the evolution of human cultures people have used plants in many other ways besides for food. Dimbleby (1977, 1978), Ford (1979), and Smith (1985) all point out that past cultures have used plants in many diverse ways. These include using plants to make clothing, bedding, shelters and supports for shelters, as tools, storage containers, weapons, shoes, ornaments, medicines, as armor for protection in warfare, works of art, as religious charms, as social statements (such as totem poles), transportation (boats, sleds, and carts), and for their chemical compounds such as the nicotine in tobacco or caffeine in tea.

34. As noted, the PDB is the actual record of all these types of uses of plants by mankind. However, since plants are used in so many different ways and for so many different purposes, it is nearly impossible to extract a complete or an accurate PDB only from an examination of either the SDB or TDB. These reasons are explored below.

Secondary Data Base

35. The size and diversity of the botanical SDB of any archaeological site is dependent upon four critical factors: 1) to what degree botanical materials were used at a site, 2) what portion of those materials have remained preserved at a site, 3) how extensive a site was used (number of people and length of time), and 4) what types of subsequent events occurred which could have altered and disturbed the original data.

36. Preservation. The preservation of botanical remains at any archaeological site is dependent upon the severity of two destructive processes: 1) reduction, and 2) decomposition. In some cases the process of decay may be so complete at an archaeological site that all of the organic plant remains may be missing due to severe reduction and/or oxidation. Even under circumstances this extreme, some indicators of past plant use may still be present in non-organic forms of evidence. These might include charcoal, soil impressions of seeds or other plant parts, casts of plant materials in adobe or pottery, and plant crystals.

37. Charcoal is a common substance found in archaeological sites. It is a useful type of evidence because it is the carbon remains of wood that has been charred. Because charcoal is inert, it is no longer subject to decomposition even though destruction by reduction can still occur from processes such as trampling, pressures caused by the movement of soil, rupture caused by water freezing in the hollow cellular openings, or the

burrowing of animals.

38. In some areas, such as many temperate regions of the world, soil chemical and biological processes tend to destroy most forms of plant remains. However, seed impressions from wild and domesticated plants can sometimes be preserved in hardened clay which was fired to make pottery. An example of this type of evidence is noted by Jessen and Helbaek (1944) in their analysis of prehistoric and early historic sites in Great Britain. In other instances, such as the ones I saw at the George C. Davis site in east Texas, impressions of river cane in the hard, dry soils were all that remained of the plant materials which once lined a burial pit. In that instance the impressions, not the cane itself, gave archaeologists their only clue of ancient Caddo burial practices.

39. As discussed later in this report, phytoliths (plant crystals) are a third form of evidence which may remain preserved in the sediments of a site even though all organic forms of plant remains may be missing due to the processes of reduction and decomposition.

40. The types of botanical remains found at an archaeological site will depend in large part on what types of plant materials were originally selected by cultural groups and whether or not some of those remains were protected from decomposition by being charred. At the Scovill archaeological site in Illinois, Munson, Parmalee, and Yarnell (1971) constructed a scale of potential "preservability" for plant parts based upon how fragile they were (for example, nut shells vs. flowers) and how well they might char if accidentally subjected to fire or used as fuel.

41. Reduction is often viewed as the first phase of plant destruction since it is defined as the slow or rapid alteration of plant materials into smaller pieces through mechanical breakdown. Reduction is a very destructive action since it also hastens the second phase, decomposition, by creating additional surfaces which are then exposed to decay. Examples of how reduction processes might occur include: 1) twigs or leaves that are broken into pieces by humans or are animal trampling; 2) nuts and seeds which are reduced to tiny fragments by the grinding actions of people seeking the food value contained inside; 3) fibers that are weakened and reduced by chewing or stripping actions; 4) wood that has been reduced by cutting or breaking; 5) flowers that are dried and then reduced by grinding or other forms of abrasion to produce the ingredients for medicinal teas or drinks; 6) tubers and roots that are reduced by grinding and pounding actions; 7) leaves and other plant materials that are cut, abraded, and weakened by chewing; and 8) finally, after plant parts, including pollen and phytoliths, are buried the compression, freezing or movements of soil can cause further reduction. Sometimes the reduction process of organic plant remains is so complete at some sites that all that remains are

millions of tiny microscopic fragments about the size of coffee grounds. Once the organic reduction process reaches the "coffee grounds" stage, identification of plant parts is difficult and is limited to looking for certain distinctive microscopic plant structures such as cuticle and trichomes.

42. The second of these processes is decomposition, which is defined as the decay and digestion of plant materials by chemical or biological sources. A number of inorganic and organic acids and bases will dissolve cellulose or weaken it to such a degree that mechanical reduction is rapid. In addition, even inorganic plant phytoliths are subject to decomposition at some sites from being altered by fire or dissolved by certain types of chemical compounds. Many of these chemical substances exist naturally in small amounts and are carried through the soil by ground water.

43. Chemical decomposition is most common in archaeological sites which are subjected to flooding or repeated cycles of wetting and drying since these actions often bring a continuous supply of fresh chemicals into contact with buried plant remains. Under some circumstances, such as cold anaerobic conditions, inundation of archaeological sites may be beneficial for plant preservation because it might stop micro-organism activity even though some chemical decomposition might still continue.

44. Many of the same chemical agents which decompose the cellulose found in the walls of pollen grains also destroy cellulose found in other forms of plant remains. The only difference between pollen and other plant parts is that the walls of pollen grains contain additional non-cellulosic compounds which are more resistant to decay and thus preserve much longer (Stanley and Linskens 1974). For this reason, it is useful to examine some of the known examples of how reduction and chemical decomposition of pollen occurs since pollen can be used as a general index for all forms of organic plant decay.

45. In some archaeological sediments chemical decomposition of plant material, including pollen, can become the primary agent of destruction. Dimbleby (1957) studied the relationship of soil pH to the preservation of pollen grains. His experiments showed that sediments which are only slightly acidic (a pH between 6.0 and 7.0), or are alkaline, generally contain meager amounts or no preserved fossil pollen. Later, studies by Martin (1963) and Bryant (1969) demonstrated that fossil pollen sometimes can be recovered from soils with an alkaline pH as high as 8.9. However, under such conditions the total organic content of the soil is usually very low, no other organic forms of plant remains are present (except in a highly reduced form discussed earlier as "coffee grounds"), and the recovered fossil pollen is often very deteriorated and sometimes unidentifiable except at the most generalized level (Bryant 1978).

46. A decade later, Tschudy's (1969) research on the Eh (oxidation potential) of

sediments showed that Eh actually may be a more important indication of the eventual preservation or destruction of organic plant materials, including pollen, than is pH. Sediments with a negative Eh (less than 1) are deemed to be better for organic preservation since they reflect reducing environments (anaerobic). An added benefit of reducing sediments are the by-products of bacterial respiration such as carbon dioxide and hydrogen sulfide which decrease the pH by increasing the acidity.

47. The chemical composition of plant materials also plays an important role in determining whether or not those materials will remain effectively preserved in various types of archaeological sediments. Of the three main compounds found in the walls of plant cells cellulose is the easiest to oxidize, lignin is more resistant, and sporopollenin is the hardest to oxidize. Havinga (1964, 1984) reported that the ratio of sporopollenin to cellulose in the walls of pollen grains directly affects susceptibility and eventual destruction through oxidation. He found that pollen grains having higher amounts of sporopollenin in their walls tended to remain preserved much longer than pollen grains with walls composed mostly of cellulose. From these data we learn that as a general rule the lower the amount of sporopollenin in the outer wall of a pollen grain, the quicker it will be decomposed by oxidation. This is why for many archaeological sediments the amount, kind, and condition of fossil pollen is often a good guide to the overall level and potential for organic preservation.

48. Experimental tests by Holloway (1981) showed that a number of specific chemical compounds can be classified as important plant decomposition agents. Holloway's study revealed that nine chemical compounds caused the highest degree of fossil pollen decomposition. Of these nine compounds, six contained chlorine, three contained magnesium, two contained potassium, four contained sodium, and three contained carbonates. Eight of the nine compounds are basic, which confirms Dimbleby's (1957) hypothesis that alkaline conditions appear to have a detrimental effect on the preservation of organic material, including pollen.

49. Holloway's (1981) experiments also revealed another important aspect about the decomposition of pollen grains, and by inference, other forms of plant remains. He found that when pollen grains are subjected to alternating periods of wetting and drying, the result is rapid reduction and an increased susceptibility to decomposition. These data suggest that the destruction of botanical remains in the soils of certain types of archaeological sites, such as those which are periodically flooded by rivers, lakes, or reservoirs, will be severe. In addition, these data suggest that at sites located in regions of the world where large amounts of rainfall are common (sub-tropics and tropics), finding

preserved botanical remains, except phytoliths, will be the exception, not the rule.

50. Decomposition of plant materials from biological sources is often a far more serious problem than is chemical decomposition. These agents include a wide variety of soil organisms and microorganisms which feed on decaying plant materials. Dead plant material serves as the primary food source for a wide variety of soil organisms such as earthworms, millipedes, ants, termites, springtails, and mites (Wallwork 1970). However, it is the microorganisms, fungi and bacteria, which are nature's most effective decomposers.

51. In archaeological sites a key factor determining whether botanical remains will remain preserved depends upon how favorable the soils are for the growth and survival of bacteria and saprophytic fungi (Dimbleby 1978). For either form of microorganism to exist in archaeological sites, conditions must be ideal. First, available oxygen and moisture levels are critical. Enough moisture and free oxygen must be present for fungi and bacteria to be able to: 1) reproduce, 2) produce enzymes that digest plant materials, 3) move effectively from one location to another in search of additional food, and 4) prevent dehydration. Proper temperature is another important factor needed for successful microorganism activity. Most fungi and bacteria can reproduce and survive within certain temperature extremes yet operate at optimum levels within even narrower temperature ranges. Soil pH also plays an important role in the survival and growth of micro-organisms. Many bacteria flourish best in neutral or basic environments and are not able to survive in soils with an acidic pH. On the other hand, many fungi prefer acidic conditions and thus become the primary plant decaying agents in acidic soils (Smith 1955).

52. One way to illustrate the results of different types of reduction and decomposition processes is to discuss these aspects as they might affect different types of sites. Since this report pertains to specific problems which might apply to the recovery and preservation of sites under the jurisdiction of the Corps of Engineers, I have tried to select site examples which are appropriate.

53. The first example is a large rockshelter, called Hinds Cave, which was carved out of the limestone walls along a tributary near the mouth of the Pecos River in what is now southwest Texas (Shafer and Bryant 1977, Shafer 1986). Although this site is located just above the flood pool level and thus was not flooded by the rising waters of the Corps' nearby Amistad Reservoir, Hinds Cave is now more accessible to boaters, relic hunters, and fishermen who use the newly created recreational facilities of Lake Amistad.

54. For more than 9,000 years small bands of human occupants lived in the powder-dry conditions of Hinds Cave. Because of the region's hot temperature, low annual rainfall (less than 20 inches per year), and low humidity (average less than 30%) almost none of the plant remains at the site, except in the lowermost levels, were destroyed by

chemical or biological decomposition. However, losses of some plant remains from earlier occupational zones may have occurred through the process of reduction as the result of trampling, fire hearths, and the other cultural activities of mankind. To a minor degree the burrowing of rodents also led to some plant destruction and some mixing of deposits. In such a depositional environment, without adequate moisture, chemical and biological decomposition could not occur once the plant materials became dessicated. Therefore, the botanical Secondary Data Base at Hinds Cave is extensive and immense.

55. Conditions were quite different at the Civil War shipwreck site of the CSS Georgia located in the Savannah River (Garrison and Anuskiewiez ms.). Factors which would affect the SDB of this site are quite different from those at Hinds Cave. For example, during the 1864 sinking process some of the wooden portions of the ship floated away. As it sank, reduction damage to its wooden hull occurred as timbers and planks broke or were split open. This event was followed by organic decomposition caused by river currents and tidal activity which carried chemical agents and biological organisms to the site. Later, other processes such as the 1866 attempt to salvage the ship's armor plating by blasting away part of the ship's hull and attempts during this century to deepen the Savannah harbor by dredging caused additional destruction and further loss of botanical materials from the shipwreck site.

56. The Devil's Mouth Site is located on a river terrace in southwest Texas at the confluence of the Devil's and Rio Grande Rivers. Excavations (Johnson 1964, Sorrow 1968) revealed that it consisted of deeply stratified alluvial soils containing artifacts of human occupation that began during the late Paleoindian era (7,000 BC) and lasted up through the late Archaic (AD 600-1,500). Judging from the botanical remains found in the deposits of nearby rockshelter sites, such as Hinds Cave, it is not unreasonable to assume that an equally rich complement of botanical remains once existed in the deposits of the Devil's Mouth Site. However, this is where the similarity between Hinds Cave and the Devil's Mouth Site ends. At the Devil's Mouth Site the soils contain a wide range of burrowing organisms. The warm, moist, and oxygen rich soils of the site provide an ideal habitat for many genera of fungi and bacteria. In addition, over the centuries other destructive factors were present. These include agents such as: 1) changing pH levels from acidic to basic, 2) Eh levels above 1.0 indicating oxidizing conditions, 3) percolation of ground water containing chemical acids and bases destructive to organic materials, 4) wetting and drying of the site's sediments from repeated flooding of either the Pecos or Rio Grande Rivers, and 5) frequent geomorphic movement of the site's soils. Alone, or in unison, each of these factors played its role in the near total destruction of the botanical

SDB at this site.

57. Site use and subsequent changes. How long a site is originally used and to what extent a site is occupied by cultural groups will influence the extent of the SDB and the kind of information that can be recovered to form a TDB analysis. Likewise, and equally important, is the subsequent change at an archaeological site after the end of its occupation period. Sometimes those later changes will have an important effect on the type of data that may later become a TDB. For example, a later cultural group which uses a once occupied archaeological site might alter, remove, or disassemble materials that were left behind by a previous culture. These later groups might dig a storage or burial pit into earlier deposits, they might collect wood found at a site and burn it, they may remove rocks from an old hearth, or they might find several broken lost dart points or stone knives and retouch the edges and use them again. Although this is only a brief look at the potential post occupation modifications that might occur, it serves as an example of how subsequent activities may alter the original context of data at an archaeological site.

58. To illustrate these points I have used several examples of actual sites. As mentioned earlier, Hinds Cave is a large rockshelter 37 x 23 meters in area (Shafer and Bryant 1977). From our excavations in various areas of the site we learned that during its 9,000 years of occupation numerous small bands of hunters and gatherers probably used the site almost on a continuous basis. Since the area surrounding Hinds Cave is full of a wide variety of plant foods and the local large game population (deer, antelope, bison, rabbits) is sparse and difficult to hunt, it appears that the rockshelter's inhabitants focused their subsistence patterns mostly on plant foods. This aspect, combined with a lack of decomposition at the site, accounted for a large and diverse botanical SDB.

59. A major problem at Hinds Cave was the size of the SDB and our discovery that the botanical information contained in the SDB varied from one area of the site to another. We discovered, for example, that certain activities were carried out in different areas of the shelter. Along the back wall at the south end of the shelter there were a number of pits which served as communal latrines. Near the interior central portion of the site we found numerous fire hearths and large quantities of plant remains generally associated with the processing and preparation of food. Near the central back wall of the site were shallow grass-lined pits which we think were used for sleeping. Near the front of the site, and extending down the talus slope beyond the drip line, were fire pits, thousands of burned rocks (used to steam foods), and large quantities of aboriginal "trash" composed of worn out or broken items of their material culture and all sorts of discarded plant refuse.

60. In addition to the obvious variations in the amount and kind of botanical remains deposited in each area of the site, the SDB at Hinds Cave was further complicated

by a series of other events which occurred after the site's initial occupation. These included: 1) in some areas of the site later prehistoric cultural groups dug storage and sleeping pits into earlier stratified levels, 2) rodent activity brought some botanical debris into the shelter and mixed deposits in other areas, 3) birds occupied nests in the ceiling of the shelter and debris from their nests probably fell into the site, 4) a family of owls periodically occupied the site and added faunal debris from their kills, 5) a few mammal predators left portions of their kills in the deposits of the site, 6) domesticated sheep used the shelter in recent times and trampled botanical remains in the upper levels of the site, and 7) relic hunters dug holes and mixed deposits in some areas of the site during the past two decades in their attempts to recover artifacts for their private collections.

61. An underwater archaeological site, such as the CSS Georgia shipwreck, had a different set of problems which controlled the size and diversity of its botanical SDB. First, the ship was scuttled by a small crew. Once it sunk there was no further interaction with humans except for salvage attempts and later ship channel dredging and excavations by archaeologists working for the Corps of Engineers. Unlike Hinds Cave, there was not a continual accumulation of plant debris at this site over a long period of time. Second, as the confederate ship sunk in the Savannah harbor, part of its botanical record floated away. As the strickened ship sunk, other debris fell out and settled in the mud at the bottom of the Savannah River (Garrison and Anuskiewiez ms.).

62. The CSS Georgia site was not occupied by later cultural groups who might have added additional botanical deposits to the site. However, two years after the ship sunk, salvage attempts to remove the armor plating was conducted by blasting away portions of the ship's hull. This process resulted in the recovery of 80 tons of iron plating and the scattering of much of the ship's original contents onto the nearby seabed (Garrison and Anuskiewiez ms.). In the 103 years since the sinking occurred, river and tidal currents, burrowing marine organisms, and a number of harbor dredging operations have each altered the available botanical SDB of the archaeological site.

63. Alluvial terrace sites, such as the Devil's Mouth Site, are often occupied many times since terraces are ideal locations for campsites. Archaeological evidence from the Devil's Mouth Site (Johnson 1964, Sorrow 1968) records an almost black and white separation of occupational levels (the culturally sterile river sand levels were light tan in color while the charcoal stained cultural levels were gray) suggesting that the site was occupied, abandoned, and flooded many times.

64. At the Devil's Mouth Site a number of events occurred, and others could have occurred, which altered the botanical SDB. Many of these events characterize the types of problems one finds associated with almost any open site. These include: 1) the botanical

materials can be trampled and scattered by animals once a site is abandoned, 2) some of the botanical materials such as pollen, phytoliths, leaves, and other fragile plant parts can be blown away by winds, 3) sheet runoff from heavy rains or the flooding of nearby streams can remove earlier deposits containing botanical materials and redeposit some of them in younger strata, 4) fires can sweep across and burn botanical remains still exposed on the abandoned surface of a site, 5) ants, termites, earthworms, and other burrowing organisms can reduce and/or relocate the plant materials from one level to the next in a site, 6) botanical materials can fall down soil cracks or root holes into earlier levels or can be relocated to some degree by geomorphic soil movement, 7) later cultural groups can dig pits into earlier levels thereby mixing debris from different strata, and 8) finally the length of time that an open site and its sediments are exposed to various reducing and decomposing agents the less botanical material generally remains as part of the SDB.

Tertiary Data Base

65. There are a wide range of factors which effect the size and type of TDB recovered from an archaeological site. These include: 1) the size, type, and condition of the SDB; 2) the percentage of the site that is excavated; 3) the method of excavation; and 4) the portion of the recovered botanical remains that are examined and analyzed. The botanical remains recovered from Hinds Cave, for example, provide an ideal example to illustrate some of the problems associated with the recovery and analysis of botanical TDBs.

66. In the three field seasons that the Hinds Cave was worked, a total surface area equal to less than 5% of the actual occupational area covered by the site was excavated. From the area excavated, the wealth of preserved botanical remains was staggering. During the longest field season, 1976, the recovery was more than 1,000 human coprolites, over 800 large No. 12 grocery sacks of botanical macrofossils, hundreds of perishable artifacts, and dozens of soil samples for pollen and phytolith analyses. Even so, all of the botanical macrofossil materials encountered could not be saved because of the total enormity of those deposits.

67. Throughout the excavations at Hinds Cave all of the excavated sediments were screened through two screens, one with one-quarter inch openings and the other with one-sixteenth inch openings. For each level and for each excavation unit, at least one large grocery sack full of botanical material from each of the two screens was saved. Thus for each level in each unit there were subsamples of the total excavated botanical remains, one from the coarse screen and the other from the fine screen (Shafer and Bryant 1977). Even by using these procedures it was realized that the portion of the botanical SDB that may have passed through both screens was lost. In addition, all of the excavated botanical

materials discarded from the screened portions of each level after taking our two subsamples was lost.

68. Ethnobotanically it is thoughtthat today we know quite a bit about the prehistoric peoples who once lived at Hind's Cave. Dering's (1979) macrofossil analysis identified thousands of individual plant parts, yet his TDB consisted of only 2% of the total plant macrofossils we saved from the site. A similar situation exists for the other botanical samples. To date less than 15% of the more than 1,000 recovered coprolites have been analyzed (Williams-Dean 1978, Stock 1983). Even so, the coprolite TDB for Hinds Cave represents one of the most extensive coprolite studies ever conducted. The majority of the TDB of botanical perishable artifacts (matting, baskets, sandals, twine, arrow shafts, digging sticks, fire starting sticks, etc) recovered from Hinds Cave have been analyzed and form an extensive report outlining many aspects about the material culture of the original inhabitants (Andrews and Adovasio 1980). The present fossil pollen TDB for Hinds Cave is based on less than one-half of the collected samples (Shafer and Bryant 1977, Dering 1979) and as yet none of the plant phytolith studies have been attempted.

69. The aforementioned discussion of Hinds Cave is a rare situation in archaeology since the problem was not trying to find a paleoethnobotanical TDB to analyze, but trying to decide which tiny portion of the recovered materials should be set aside to form TDBs. As in most archaeological projects, the limits were based on time and funding levels of the project. An excellent discussion of general types of sampling problems one must consider is found in the article by Collins (1975).

70. When the wreck of the CSS Georgia was located and excavated by archaeologists working for the Corps of Engineers (Garrison and Anuskiewiez ms.) a number of artifacts were recovered including a structural timber that was approximately 8 x 12 in. in cross-section when it was used as part of the ship's hull. The timber showed extensive damage from the agents of decay and boring organisms. Most of the outer sapwood portion was destroyed and only the more resistant heartwood portion remained undamaged by either decay or worm action. Eventual analysis revealed that the timber was made of pine but the precise species could not be determined.

71. In another portion of the shipwreck site Garrison and Anuskiewiez (ms) found strap shot intended for use in one of the ship's cannons. Strap shot was a common form of Civil War shell and were stored in wooden sabots. When the strap shot specimens were found at the CSS Georgia site all but one of them were missing their wooden sabots. One of the strap shot specimens had a small piece of wooden sabot that was recovered but it was badly decayed, suggesting that other sabot holders were either lost to decay or floated

away soon after the ship sunk.

72. The paleoethnobotanical TDB from the Devil's Mouth Site is almost nonexistent (Johnson 1964, Sorrow 1968). Whatever fruit pits, bark, leaves, nut shells, root fibers, wood, flowers, fruit rinds, and seeds may have been discarded have all decayed or were carried away by later flooding actions of the Pecos or Rio Grande Rivers. Most of the pollen deposited in the soils of the site had oxidized; however, some pollen did remain preserved and was analyzed (Bryant and Larson 1968). Of all the botanical materials which were originally deposited as part of the cultural actions of the people who once used the Devils Mouth site only a few items remain such as pieces of badly broken charcoal, limited numbers of fossil pollen grains, and probably inorganic phytoliths. No attempt to recover or analyze phytoliths was ever attempted before the site was inundated in the late 1970's.

73. For each of the three sites mentioned above the botanical TDB is quite different. In one example the problem was having too much botanical material to analyze effectively. In the other two examples the remaining botanical material was meager at one site and almost nonexistent at the other. The reasons for the great differences in the TDBs from these sites are related directly to the points I have already mentioned. These are: 1) the size, type, and condition of the SDB; 2) percentage of the site that was excavated; 3) method of excavation; and 4) portion of the recovered botanical remains which was examined and analyzed.

Recommendations

74. Suggesting recommendations on how to best preserve botanical material in archaeological sites scheduled to be altered or affected by land modification processes, such as the construction of a reservoir, is not easy. The primary problem is that almost any form of archaeological site alteration will damage the existing record of plant remains. As I have discussed below, some types of botanical remains are preserved better under specific types of chemical and physical conditions. For other types of botanical materials a different set of environmental factors are more nearly ideal for successful preservation.

75. Often there exists a situation where no matter what type of land modification effort is attempted at an archaeological site, the result will be detrimental to the existing botanical record. With this in mind, I feel that in most cases the only satisfactory solution is to attempt to excavate and recover as much of the botanical record as possible at archaeological sites before the sites are altered by land modification projects.

76. In the section below I have tried to outline some of the positive and negative factors which affect the preservation of botanical materials deposited in archaeological

sites. Most of these factors occur naturally in the environment. The effects of many of them, such as the effect caused by repeated wetting and drying, often will be increased and speeded up after the modification of an archaeological site's natural environment caused by reservoir building and subsequent flooding.

77. The primary factors considered to be the most important in the preservation or decay of botanical materials in archaeological sites are:

Acid environment

78. In most cases an acid soil environment will enhance the preservation of plant materials. Most acid environments, such as those found in some bogs and swamps have resulted in an excellent recovery of all types of botanical materials including fossil pollen, plant macrofossils, charcoal, and phytoliths. A recent illustration of this is documented in the British study of Lindow Moss, a large bog located in Cheshire, England (Stead, Bourke, and Brothwell 1986). In that study scientists noted that the bog's acidic and anaerobic conditions resulted in the excellent preservation of fossil pollen, plant macrofossils, charcoal, insect remains, and prehistoric human bodies which were so well preserved that detailed analyses were possible of their tissues, hair, nails, stomach and intestinal contents, and body parasites. In general, increasing the acidity at an archaeological site will aid the preservation of the site's botanical remains.

Basic environment

79. A basic, or alkaline, condition is generally detrimental to the successful preservation of botanical remains in archaeological sites. As mentioned earlier in this report, and documented many times in the available literature (King 1975, Ford 1979, Bryant and Holloway 1983), the recovery of preserved botanical remains from archaeological sites with alkaline soils, or from lake deposits with a basic pH, is marginal at best. Any alteration of an archaeological site's deposits which will increase the alkalinity or change a site's soil pH value from acidic to basic will cause severe damage to the existing botanical record. Unfortunately, the effect of archaeological site flooding caused by reservoirs often tends to increase the alkalinity of sites which previously had acid pH soils.

Dry and wet/dry environments

80. Dry environment. A dry environment is ideal for the preservation of all types of botanical remains. The archaeological record is full of reports and analyses of the diversity and wealth of botanical remains that can be recovered from dry archaeological sites (Saffray 1876, Towle 1961, Helbaek 1963, Shafer and Bryant 1977, Dimbleby 1978, Ford 1979). As noted earlier in this article, our problem at Hinds Cave was not finding botanical material, but trying to determine how much of the botanical record could be analyzed within the time and funding limits of our project. As in the Hinds Cave situation,

archaeologists working at dry sites are generally confronted with the problem of recovering too much, not too little, botanical material. Any type of modification to the environment of an archaeological site which causes the site to become drier is generally considered advantageous for the preservation of botanical remains.

81. Wet/dry environments. Of all the various factors which affect the eventual preservation or decay of botanical materials in archaeological sites, one of the most detrimental is a cycle of wetting and drying of the site's sediments. At the Hershop Bog (Larson, Bryant, and Patty 1972) we found excellent fossil pollen and plant macrofossil preservation in levels of the bog which had been continuously wet. On the other hand, in the upper few feet of peat at Hershop Bog, where ditches had been dug in an attempt to drain the area, the resulting cycles of wetting and drying caused a total decay and destruction of the preserved pollen and smaller plant macrofossils. In a similar situation, the cycles of wetting and drying created by an intermittent spring at the Levi Site caused the total loss of all botanical remains except for phytoliths (Bryant 1969). There is one final point on this subject which needs consideration. Earlier in this article I explained that cycles of wetting and drying at archaeological sites cause more damage to the botanical remains than either continuous wetting or continuous drying. This point is especially important to consider when assessing the effects of reservoirs upon archaeological sites located near the surface of flood pool levels. If reservoir levels rise and fall enough to cause nearby sites to become wetted and then dried, the detrimental effects of this sequence upon the botanical remains will be extensive.

Wet aerobic/wet anaerobic environments

82. Wet aerobic. Wet aerobic environments, which are characteristic of many shallow lakes and many newly constructed reservoirs, are ideal habitats for many forms of plant eating microorganisms such as bacteria and fungi. In addition, wet aerobic environments are the favored habitats of a number of small marine organisms which feed on decaying plant material. In studies of the decay process of pollen placed in aerobic deposits in lakes, Sangster and Dale (1961) noted that the rate of decay in those deposits were significantly faster than rates of organic decay in dry land sediments. If archaeological sites are inundated in an attempt to preserve them, all hopes of preserving their botanical records will be quickly lost if the lake or reservoir is aerobic.

83. Wet anaerobic. In my previous discussion of acid environments I noted the excellent degree of botanical preservation recovered from the Lindow Bog in England (Stead, Bourke, and Brothwell 1986). As noted by the authors of that report, a key factor leading to the successful preservation of both plant and animal remains in those deposits was the anaerobic conditions of the bog sediments. Similar testimony about the excellent

preservation of botanical materials in wet anaerobic conditions is noted by Heer (1865), Dimbleby (1978), and Godwin (1981). Any form of modification to archaeological sites which will create a constant wet, and at the same time anaerobic condition, will enhance the preservation potential for botanical remains. Unfortunately, the wetting of archaeological sites caused by most forms of reservoir construction creates an aerobic, not an anaerobic, depositional environment.

Compression and sediment movement

84. Compression. Compression of deposits in archaeological sites will cause detrimental effects to most botanical remains. Charcoal fragments, which generally can be identified, are broken and crushed by compression. Seeds, pieces of wood, fruit remains, and nuts often break or their shapes and morphological features become severely distorted when compressed. Only pollen and phytoliths sometimes escape damage from the forces of compression. If burying archaeological sites under tons of rock or rubble is considered as a method of site preservation, one needs also to consider the types of damage such processes might have on some of the site's contents, such as the botanical remains.

85. Sediment movement. Sediment movement in archaeological sites has the same type of detrimental effect on botanical remains as does compression of site sediments. Sediment movement, caused by factors such as freezing and thawing or wetting and drying, often places unequal stresses on various parts of a botanical specimen. For example, a small twig, piece of charcoal, or nut shell might have lateral forces pushing part of it in one direction and the rest of it in another direction. This type of circumstance could cause breakage or shape deformation. In addition, sediment movement can often cause a disassociation of some botanical remains. In areas where sediment movement is common, such as sites in the Arctic, it is common for some botanical remains to be moved from their original point of deposit in one level, or stratum, to a different level or stratum. Such movements of botanical remains can create later problems in analysis if the materials are excavated and used for interpretive purposes.

Microorganisms and macroorganisms

86. Any circumstances which will increase the activity of either microorganisms or macroorganisms in the sediments of archaeological sites will be detrimental to the botanical remains of that site. Many species of soil dwelling bacteria and fungi and a wide variety of macroorganisms rely upon organic matter as a source of food. As mentioned earlier in this report, experiments by Sangster and Dale (1961) and Holloway (1981) have noted that increased microorganism activity is one of the primary causes leading to the destruction of pollen and, by inference, other types of plant remains in soils. In other studies Goldstein (1960) and Dimbleby (1978) have also examined the detrimental effects

caused by various types of microorganisms and macroorganisms upon buried plant materials. Thus, any type of modification to the sediments, or changes in the environment of deposition, of an archaeological site which increases the activity levels of microorganisms and/or macroorganisms should be viewed as detrimental to the preservation of botanical remains.

Freeze-thaw cycles:

87. Freezing can damage botanical remains in archaeological sites because water tråpped in the cellular openings of plant remains, or charcoal, expands when it freezes. If the forces of expansion are strong enough, they can rupture the cellular walls of plant material or break pieces of charcoal into small fragments. This type of effect can damage plant material regardless of whether the plant is living or dead. Once freezing has ruptured cellular openings, the effected material is much more susceptible to the forces of reduction. In areas where cycles of freezing and thawing are common, soils often contain millions of tiny pieces of plant debris. The result of this type of reduction process often leads to the formation of "coffee grounds"; so called because the remaining plant debris is often no larger than coffee grounds. Thawing generally does not injure plant material; the damage has already been done by the freezing process.

Summary

88. Paleoethnobotany is not an exact science. Instead researchers in this discipline are like detectives who have arrived on the scene of a crime long after it has occurred. These detectives, like paleoethnobotanists, must scurry about at the "scene of the crime" searching for the tiniest of clues in order to recreate what seems like a logical sequence of events such as: 1) explaining what the crime was, 2) who committed it, and 3) what happened to all the participants who were involved. In both cases, for detectives and ethnobotanists, the ability to recreate what really happened is only as good as the evidence that remains and the ability of the investigator to make logical sense out of the clues which still exist.

89. The clues used by paleoethnobotanists come mostly from archaeologists since they are trained to excavate sites and uncover the clues related to the activities of past cultures. As mentioned in earlier sections of this article, ethnobotanical clues come in many forms and the type and number of clues which exist at any archaeological site depend upon a myriad of conditions and situations. I noted that types of botanical clues include a wide variety of plant macrofossils, charcoal, fossil pollen, and plant phytoliths. In addition, human coprolites offer some of the best clues available concerning the foods which were

eaten, how foods were prepared, and the nutritional value of human diets. How many of these botanical clues will be available at a site varies on factors such as: 1) the amount of plant material that was used by a culture for everything from subsistence and building their shelters to making their clothing; 2) the number of people who occupied a site since larger groups generally use more plant material; 3) the length of time a site was occupied by cultural groups; and 4) what has happened to the site in the years since it was abandoned.

90. Being a paleoethnobotanist and working with the fossil remains of plant materials from archaeological sites is both exciting and frustrating. The excitement comes from finding tiny clues of botanical information and piecing them together like the parts of a puzzle until you think you begin to get a glimpse of the whole picture of what happened and how plant materials were utilized by some extinct culture. The frustrations of the discipline are often as intense as the excitement. Working at some archaeological site and finding just enough clues to make the botanical search interesting, but not finding the right kinds of clues or not enough clues to get a clear glimpse of the whole picture becomes a nightmare of frustration.

91. What hopes exist for the future of paleoethnobotany? As I outlined in my discussion of the historical development of the discipline, great progress has already been made in the discovery of new methods of recovery, better analytical techniques, and more sophisticated methods of interpretation. Today, and in the years to come, we will be able to enhance our interpretations based on: 1) developing new techniques for recovering botanical remains, 2) learning new applications of computer analysis, 3) using new methods of trace element identifications, 4) discovering new applications of scanning electron microscope analysis, and 5) recognizing a better understanding of plants and how cultural groups used them.

92. In closing, I would like to focus on a more somber note. The future of paleoethnobotanical analyses, geoarchaeological analyses, zooarchaeological analyses, lithic analyses, material culture analyses, and a host of other studies is dependent upon one critical factor: the availability of archaeological sites from which these data can be extracted. Without the preservation of these sites and the materials they contain the record of past cultures will be lost for our generation and all future generations. It is for this reason that all of us, regardless of subdiscipline within the field of archaeology, must work towards a common goal of encouraging site preservation and the comprehensive recovery of data from archaeological sites about to be destroyed, altered, or investigated.

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AN INTRODUCTION TO GEOARCHAEOLOGY AND THE IMPACTS OF SITE BURIAL

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Introduction

1. Geoarchaeology is a new and emerging subfield within archaeology concerned with the geological interpretation of archaeological sites and sediments. Geoarchaeology incorporates geomorphology (the study of landform origin and morphology), stratigraphy (the study of sediment layering and sequencing), sedimentology (the study of sediment particles to reconstruct environments), paleopedology (the study of soil formation and morphology), and geochronology (absolute dating of sediments) into a unified approach to archaeological site investigation. The principle objectives of geoarchaeology are to: (1) determine the geological processes responsible for the formation (burial and preservation) of archaeological sites; (2) reconstruct the physical environment and landscape of archaeological sites; (3) evaluate the geological and biological processes responsible for the modification and destruction of archaeological deposits and contexts before and after burial; (4) establish the site microstratigraphy and geochronology and place the site within its larger regional stratigraphic setting; and (5) reconstruct the regional late Quaternary history of landscape and environmental change before, during, and after occupation of sites to elucidate the dynamic relationship between humans and their physical environment.

2. The interpretation of the geological aspects of an archaelogical site is one of the most vital parts of archaeological research. Many site-specific and regional archaeological questions such as the entry of humans into the Americas, physical environmental factors affecting the origin of agriculture, site abandonment, and others cannot be resolved without understanding the relationship of geology to archaeology. As stated by Renfrew (1976), "every archaeological problem starts as a problem in geoarchaeology," because prehistoric archaeology recovers almost all its basic data by excavation from a complex matrix of sediments and soils. Geoarchaeology is not just simply an ancillary aid, but instead it is an indispensable tool of archaeological research.

3. I define geoarchaeology as the application of methodologies and concepts from the geosciences to archaeological research problems. This is similar to the definitions proposed for both geoarchaeology and archaeological geology by other researchers, who differentiate between these terms. Although numerous definitions have been proposed (Renfrew 1976; Gladfelter 1977, 1981; Hassan 1979) the definitions proposed by Butzer (1980, 1982) and Rapp and Gifford (1982, 1985) are the most pervasive in the literature.

4. The term archaeological geology has been championed by Rapp and Gifford (1982, 1985). They define archaeological geology as "the application of geologic principles and techniques to the solution of archaeological problems." They believe that archaeological geology represents a discrete discipline within the field of geology.

5. Butzer (1980, 1982) on the other hand, champions the term geoarchaeology and defines it as, "archaeological research using the methods and concepts of the earth sciences." Geoarchaeology is seen as part of archaeology allied with the other subfields of zooarchaeology, archaeobotany, and archaeometry to elucidate the prehistoric environment. By this definition, geoarchaeology is but one tool utilized for environmental reconstruction. Butzer (1980, 1982) incorporates all these subfields, including geoarchaeology, within the larger theoretical framework of human ecology or environmental archaeology whose ultimate purpose is to understand the dynamic interaction between humans and the environment. Butzer (1980, 1982) feels that archaeological geology contrasts sharply with geoarchaeology. He would define archaeological geology as "geology pursued with an archaeological bias or application." The goal or emphasis of the geological investigations creates the distinction between geoarchaeology (geology pursued with an archaeological application) and archaeological geology (archaeology pursued with the help of geology).

6. Implicit in both these definitions is the application of geological concepts and methodologies to archaeological problems. No one would argue that the key issue is geology helping archaeology. Regardless of whether we call it archaeological geology or geoarchaeology, it is still the same. Perhaps this argument over terminology was best summarized by Farrand (1985, 1986) who stated that whether one takes the label of archaeological geologist or geoarchaeologist may be determined by the academic department in which he or she is employed. This debate has gone on too long, and whether you call it geoarchaeology or archaeological geology, it is still the interdisciplinary cooperation between geologists and archaeologists to resolve archaeological questions that matters.

7. Geoarchaeology, the term I have chosen to use, may best be defined as the application of methodologies and concepts from the geosciences to archaeology. The word geoarchaeology emphasizes the "geo" component of the archaeological record in much the same way that bioarchaeology, zooarchaeology, and archeometry denote their subfields within archaeology. True geoarchaeological studies are an integral part of archaeological research in the endeavor to understand the evolution of human culture.

The Geoscience Tradition Within Archaeology

8. The ultimate objectives of archaeology are: (1) the construction of culture history, (2) the reconstruction of past lifeways, and (3) the understanding of culture process. Examination of these goals indicates that archaeological investigations, by its own admission, must be interdisciplinary. Archaeology has had a long history of incorporating the methodologies and concepts of other disciplines for the investigation and interpretation of the past. For example, techniques for chronometric dating, determining the provenance of materials from archaeological sites, and prospecting for sites and buried remains on a site, were ultimately derived from physics and chemistry. This specialized cooperation between the physical sciences and archaeology has given rise to a subdiscipline within archaeology known as archaeometry. Methods for the reconstruction of past floral and faunal communities have been derived from biology and zoology. This interdisciplinary cooperation has become so successful that it has given rise to the subdisciplines within archaeology known as archaeobotany and zooarchaeology. These subdisciplines of archaeology, offspring of the physical and biological sciences, are true subdisciplines within the broader field of archaeology. Practitioners of these subfields devote almost all their efforts to archaeological research.

9. In this regard, perhaps one of the longest relationships has existed between the geosciences and archaeology, and yet it is one of the last subdisciplines of archaeology to emerge. This relationship has been reciprocal and beneficial to both disciplines. The role of the geologists and the contributions made by geological investigations at archaeological sites have expanded through time and show a close relationship to the growth and development of the field of archaeology, providing such concepts as uniformitarianism, geologic time, and especially the principles of stratigraphy on which archaeological excavation is predicated. The following brief review demonstrates the close ties between geology and archaeology through time. It is by no means comprehensive and more detailed discussions of the development of geoarchaeology can be found in Rapp and Gifford (1982) and Gifford and Rapp (1985a, 1985b).

10. During the eighteenth and nineteenth centuries, European archaeology was deadlocked - the authenticity of artifacts and the understanding of the antiquity of the human race was limited by religious doctrine. This deadlock was partially overcome by the hard work of early archaeologists and Darwin's theory of evolution, but the logjam was undone by geology. Geology provided the key concepts of uniformitarianism, geologic time (great time depth), and the principle of stratigraphic succession. These concepts provided the foundation for the acceptance of human antiquity in the Old World and for understanding the evolution of humanity and its cultures. Charles Lyell, the father of the doctrine of uniformitarianism and modern geology, in The Geological Evidences of the Antiquity of Man published in 1863, systematically demonstrated that stone tools occurred within sediments deposited during the Ice Age (Pleistocene) and therefore were of great antiquity. This and other work by geologists provided the geologic framework for the development of a Paleolithic chronology in Europe

11. A similar situation led to the close ties between geology and archaeology in North America. One of the early debates in North American archaeology, during the late nineteenth and early twentieth centuries, centered around the first arrival of humans to the New World. The geologist's role in this debate was again to interpret the stratigraphy, validate the context of artifacts, and determine the chronological placement of sites. The debate over the antiquity of humans in North America continued until 1927, when prehistoric implements were found in direct association with extinct Bison antiquus within undisturbed geologic deposits. Figgins (1927) noted that geology provided the necessary bridging argument to conclusively demonstrate the Pleistocene antiquity of humans in North America.

12. With the establishment of human antiquity in the Americas to the terminal Pleistocene, the emphasis in archaeology for the next three to four decades turned to building regional cultural chronologies, in an effort to establish a prehistoric data base. This archaeological research effort led to the traditional role of the geologist at archaeological sites - establishment of site stratigraphy and estimates of site age. Two notable geologists made a great impact during this era and may be considered the fathers of American geoarchaeology - Kirk Bryan and Ernst Antevs. Others, such as E.H. Sellards, also made significant contributions to geoarchaeology, but Bryan and Antevs dominated the field of geoarchaeology from 1925 to 1950.

13. Kirk Bryan, a professor of geology at Harvard University, and his students were responsible for much of the early geoarchaeological research in North America. Bryan and his students studied the deposits and geochronology at such important early man sites as the Lindenmier Folsom site, Colorado; Sandia Cave, New Mexico; Ventana Cave, Arizona;

and the San Jon site, New Mexico. Bryan characterized the artifact-bearing deposits and estimated the age of these early sites by correlation of the site stratigraphy with his alluvial chronology for the American Southwest or the North American glacial sequences. For example, the age of the Lindenmier Folsom site was estimated to lie between 25,000 and 10,000 yr B.P. by Bryan, based on the correlation of the terrace chronology on the Cache la Poudre River with the glacial sequence for the Rocky Mountains. Today the Folsom culture has been radiocarbon dated between 11,000 and 10,000 yr B.P. Bryan was also concerned with paleoenvironmental reconstruction and used this as a backdrop to understand human interactions. For example, Bryan (1941) proposed a geoarchaeological explanation for the abandonment of parts of the Pueblo area of the Southwest. He proposed that arroyo cutting and environmental degradation led to destruction of arable land that forced the residents of some regions to establish new territories elsewhere in the plateau area.

14. Most of the age determinations made by Bryan were for Pleistocene age sites. Archaeologists, now aware of the time depth of human history in the Americas, were interested in "filling in the gaps" between the ceramic period cultures and the early man finds by constructing regional chronologies. What they needed was a way to date archaeological sites within the Holocene, the bulk of human prehistory in North America. Geologist Ernst Antevs, of the Carnegie Institution, developed a method to estimate the age of Holocene artifact-bearing deposits in the arid and semiarid West based on the correlation of sediment properties to Holocene climatic events (Antevs 1955a, 1955b). This method was called geologic-climatic dating and much of his terminology of climatic change is still used today.

15. Geologic-climatic dating consisted of attributing a deposit with archaeological remains to a particular dated climatic period. A relative regional climatic history for the West was deduced from a variety of data and roughly dated by correlation to the North American and Finno-Swedish varve chronologies. The climatic episodes defined by Antevs were, from oldest to youngest: subhumid Provo Pluvial (more than 14,000 to 10,000 yr B.P.), semiarid Anathermal (10,000 to 7,500 yr B.P.), arid Altithermal (7,500 to 4,000 yr B.P.), and semiarid Medithermal (4,000 yr B.P. to present). Fundamental to the geologic-climatic dating method is the dependence of geological processes, and thus the physical characteristics of a deposit, on vegetation and specific climatic regimes (especially temperature and moisture). For example, Antevs considered distinctly laminated deposits indicative of subhumid Pluvial age sediments. He also believed that calcium carbonate accumulation occurred during the arid Altithermal. The parent deposits in which the calcium carbonate accumulated and beds below the calcium carbonate-bearing strata were

interpreted to be pre-altithermal, and the deposits in channels cut into them post-Altithermal. Supplementary data were provided by vertebrate fossils and macrofloral evidence; extinct fauna indicated Pluvial sediments and modern fauna post-Pluvial sediments. Thus by examining the deposits for diagnostic characteristics and assigning the deposits to a specific climatic phase, it was possible to date an archaeological site. Many of the estimates made by Antevs were remarkably accurate. For example, the mammoth kill at the Lehner Clovis site in Arizona was estimated to have occurred about 13,000 yr B.P. based on geologic-climatic dating. Radiocarbon dates from the Clovis component now date the site to 11,000 yr B.P. Antevs characterized the stratigraphy, offered paleoenvironmental reconstructions, and estimated the age of many archaeological sites in the American West, most notably: the Blackwater Draw locality, New Mexico; the Lehner and Naco Clovis sites in Arizona; and Cochise Culture sites in Whitewater Draw, Arizona.

16. With the introduction of the radiocarbon dating technique in the 1950s, the interaction between archaeologists and geologists diminished. Geologic-climatic dating was no longer needed. Geologists were still consulted to assist with complex stratigraphic sequences, but much of the routine stratigraphic descriptions and collection of samples for radiocarbon dating were done by archaeologists.

17. During the next phase of American archaeology, beginning in the 1960s, the objective of simple data collection and construction of culture history was replaced by a more anthropological orientation to archaeology. The primary goals of archaeology shifted away from the reconstruction of culture history to an analysis of the data base which included the reconstruction of past lifeways (i.e., reconstruction of the prehistoric environment, subsistence patterns, and diet). Archaeologists assembled interdisciplinary teams of scientists to study the palynology, paleontology, zoology, and geomorphology of sites with the goal of reconstructing the paleoenvironment as a backdrop to understanding human interactions. This approach matured into trying to understand the dynamic interaction between man and his environment and the process of change. These redefined goals have led to a renewed and intensified interaction between geologists and archaeologists. This is evidenced by the publication of a number of books, such as <u>Environment and Archaeology: an Ecological Approach to Prehistory</u> (Butzer 1971), <u>Archaeology as Human Ecology</u> (Butzer 1982), <u>Archaeological Geology</u> (Rapp and Gifford 1985), <u>Archaeological Sediments in Context</u> (Stein and Farrand 1985), <u>Geo-archaeology: Earth Science and the Past</u> (Davidson and Shackley 1976), and <u>Geoarchaeology in the Northwest: Recent Applications and Contributions</u> (Willig 1984). All these books are designed to illustrate the interaction of geology with archaeology and facilitate more interdisciplinary cooperation. Other recent developments include the creation of the

Archaeological Geology Division of the Geological Society of America in 1977, and the creation of a new journal in 1986, entitled Geoarchaeology, devoted to interdisciplinary studies. This new cooperation and the integrated nature of the contact between archaeologist and geologist in recent decades has gelled into geoarchaeology.

18. No longer are geologists simply consultants called upon to interpret the site stratigraphy and geochronology. Today geoarchaeologists can offer a much fuller understanding of archaeological data obtained through survey and excavation that can be fully integrated into archaeological interpretations. However, the full range of geological concepts and methodologies that could be applied to archaeological research have not been fully appreciated or utilized by archaeologists. This is due in part to the archaeologist's lack of awareness of the contributions geoarchaeological studies could make and in part due to the geologist's failure to communicate effectively with the archaeologist. Geoarchaeology is one of the most powerful tools for site investigation that in concert with the other archaeological sciences of zooarchaeology, archaeobotany, and archaeometry can sharpen the interpretation of traditional archaeological data to more fully address archaeological research questions. Geoarchaeology is an indispensable part of archaeological research. Without geoarchaeological investigations of archaeological sites, a major component of the past environment on which man lived - the physical landscape - is missing. Geoarchaeology, as mentioned previously, also makes other valuable contributions to understanding the site matrix and nature of the archaeological record.

19. In the 1980s, archaeology has realized a balance between its three primary goals of (1) reconstruction of culture history, (2) reconstruction of past lifeways, and (3) understanding of culture process. It is clear that geoarchaeological investigations are necessary and indispensable for the achievement of each of these goals. In fact, these goals could not be achieved or effectively realized without the interdisciplinary cooperation between geology and archaeology - the role of the emerging subfield of geoarchaeology.

Geoarchaeology Applied to the Problem of Site Preservation by Burial

20. Once a site is abandoned, geological processes are primarily responsible for site destruction or burial. This process is generalized in Figure 1. In addition, biological processes are also important to the disturbance of an archaeological site prior to its burial. Archaeological remains that become buried can range from fully intact (primary context) to completely disturbed (secondary context) and which occurs depends on the geographic position of the site, length of time between abandonment and burial, and the geological

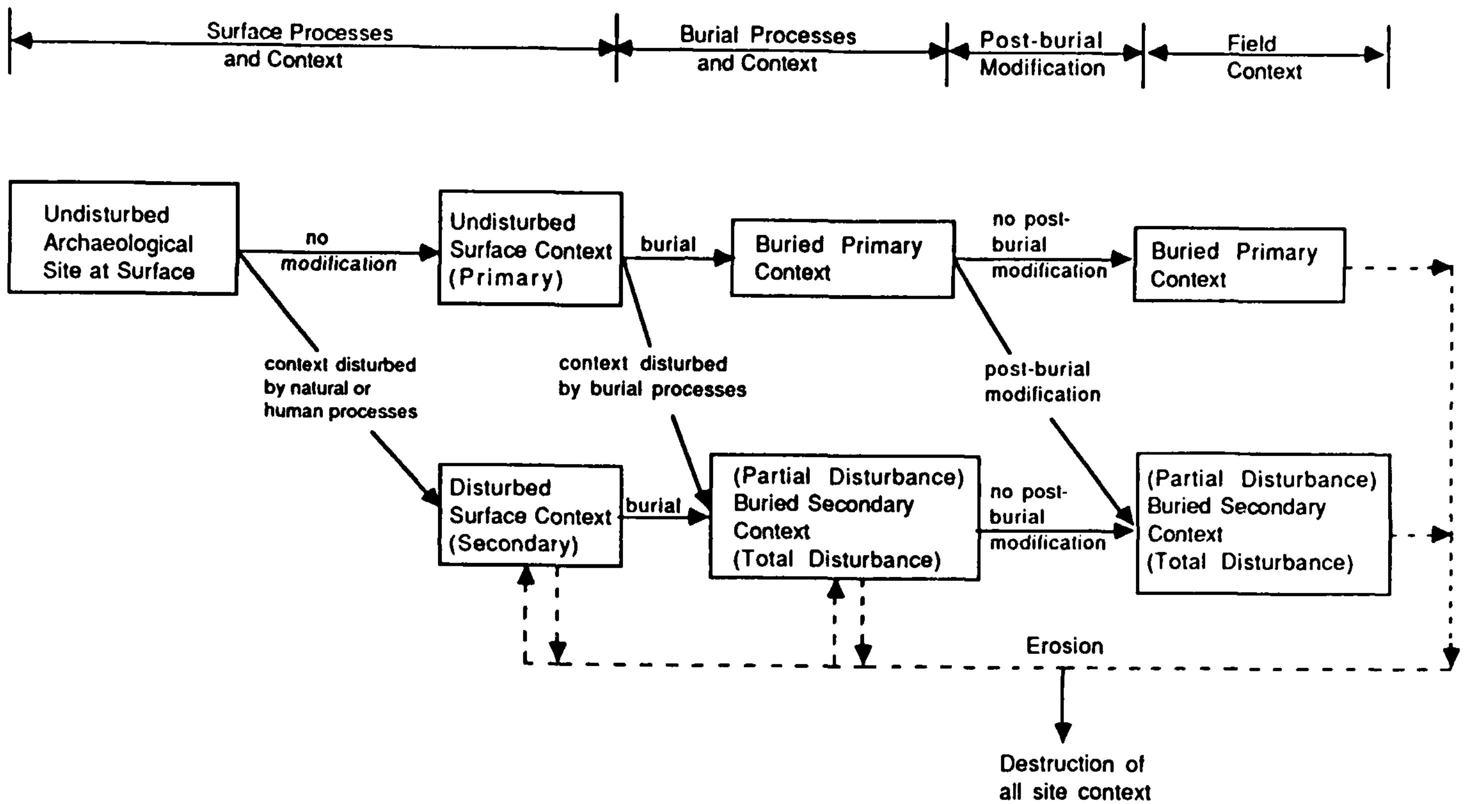

Figure 1. Model for the creation and physical modification of an archaeological site. Geochemical variables (especially water and soluble salts) are not shown, but these variables would affect the preservation of material culture and ecofacts.

processes of burial. Once buried, archaeological remains will undergo diagenesis or in situ modification by geological and biological processes. Biological processes include floralturbation (disturbance of sediments and site context by plant rootlets, falling trees, etc.) and faunalturbation (disturbance of sediments and site context by burrowing organisms). Geological processes of diagenesis and alteration can be either physical or chemical. Physical processes include the disturbance of archaeological contexts by the displacement of archaeological remains by freezing and thawing of the ground (cryoturbation), expansion and contraction of clays (argilliturbation), precipitation and expansion of salt crystals (crystalturbation), and others (Wood and Johnson 1978). Geochemical processes are primarily restricted to sediments exposed at the surface where soil formation occurs by the in situ chemical weathering and displacement of weathering products downward into the near surface profile. Groundwater also influences the geochemical environment of a site. In general, the organic fraction and more delicate material remains of the archaeological record will be most influenced by the geochemical conditions of the sediment (such as depth of leaching of water and salts). All these are natural factors influencing the burial, disturbance, and preservation of archaeological remains on a site and is the starting point of this workshop.

21. The main concern of the workshop is archaeological site preservation by burial. Therefore, it is important to understand what would happen to a site if it were intentionally buried. Two important impacts to consider in this regard are: (1) compaction of the archaeological layer by the weight of the overlying sediment used to bury it and (2) the changes in the geochemical environment within the archaeological layer brought about by burial. It is important to know how these impacts would affect the material remains and features within the artifact-bearing stratum.

22. The artifact-bearing layer or site would be compacted by the weight of the material applied over its surface and by the processes used to apply it. At least two impacts would result: (1) The nature of the sediments would be altered by increasing the bulk density (decrease in pore space due to collapse of voids). This effect may alter the inferences that could be drawn from the sediments. (2) Some damage may occur to the artifacts and ecofacts within the archaeological site. Archaeological remains such as bone and ceramics, with low material strengths, could warp and break under the increased pressure. Some factors which would affect the degree of compaction of the artifact-bearing unit or parent material would be: (1) the texture (percent of sand, silt, and clay and degree of cementation) of the parent material; (2) moisture of the parent material; (3) initial bulk density of the parent material; (4) presence or absence of soil structure within the parent material; and (5) weight, texture and thickness of material applied to cover the site. All

these factors would affect the compaction of the site.

23. The second impact resulting from intentional burial of a site would be to remove the site from its surface context and geochemical environment and place it into a subsurface context and new geochemical environment. By so doing, this may reduce the effect of natural diagenetic processes: (1) biological (faunalturbation and floralturbation); (2) physical (cryoturbation, crystalturbation, and argilliturbation); and (3) geochemical (soil formation). However, by the same token, new impacts could be introduced. For example, if the thickness of the overlying material emplaced to protect the site were not thick enough to remove it from the zone of active soil formation processes, the site could be displaced into the zone where translocated soluble salts accumulate, which would be deleterious to the preservation of organic and fragile material remains. Also, for example, in cold regions the layer burying the site may be thick enough to remove the site from the zone of active annual freezing and thawing, but it may place the site within the zone that is perennially frozen. Another possible negative impact created by burying a site could lead to enhanced stream erosion. Burial of a site will remove it from surface stream and runoff processes that could erode or damage the site. However, if the burial of the site significantly increased the slope of the landscape, this could actually trigger erosion, leading to entrenchment of the intentional cover and underlying site, resulting in the destruction of the site.

24. The main point of these few illustrations is that while removing the site from some natural impacts, you have the potential of introducing new impacts that can be either less or more negative than those that characterized the original surface context of the site. In summary, one cannot change a complex natural system without changing its delicate balance or equilibrium. The site is an open system and by the addition of material to bury the site, the old equilibrium is upset and leads to the creation of a new equilibrium. One must consider whether the new equilibrium following burial is more beneficial to the preservation of the site than the equilibrium and associated decay prior to burial. If the former is beneficial, then burial would be a desirable preservation technique.

25. Little is known about the impacts of burial on archaeological sediments or site contexts. An overview of archaeological site impacts is offered by Wildesen (1982), but does not address the preservation of sites by burial. To gain more information on the impacts of burial on archaeological sites the following could be done: (1) Summarize the existing data obtained by other disciplines (e.g., recreation specialists, soil scientists, forestry specialists, etc.) on compaction and changes in sediment geochemistry. There should be recent literature on this topic, especially with the concern over the burial of hazardous waste materials; (2) Conduct before and after studies to test and measure the

effect of burial on sites (e.g., measure the effects of burial on sites under levees and parking lots if they were measured and tested prior to burial); (3) Examine natural deep stratigraphic exposures to look at the effects of burial on artifacts (e.g., ceramics and bones); (4) Pick a site and systematically bury it with various types of materials and with different thicknesses of sediments and monitor the impacts over a series of years (perhaps this could even be modeled by computer simulation); and (5) Conduct materials testing on archaeological remains to determine thresholds for breakage and deformation.

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PHYSICAL-CHEMICAL-BIOLOGICAL PROCESSES AFFECTING ARCHAEOLOGICAL SITES AND CARBONACEOUS SAMPLES AND THEIR POTENTIAL FOR ARCHAEOMETRIC ANALYSES

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Introduction

1. The conservation of a site includes two goals which may be hard to achieve at the same time. First is to leave the original undisturbed setting for observation by future generations who should see it as a historical document. The second goal is to facilitate future scholarly research, some of which will be conducted in laboratories by analysts looking for the unaltered remains, and wishing that their predecessors had sheltered or recovered and stored samples of the site.

2. Fundamental requirements for successful laboratory studies in archaeometry will not change in a major way. As an example, future age dating specialists will be looking for the freshest sample available from the most inert and protected environment, because preservation of the molecular, isotopic, nuclear and magnetic records is important. Location of the sample discovery and context within the site are of secondary concern in laboratory studies.

Outline of the Radiocarbon Dating Method

3. Radiocarbon dating provides reliable age estimates if the analyzed sample materials fulfill the following conditions:

a. Sample formation occurs during a short time span.

b. Sample carbon originated from a carbon reservoir of known isotopic composition, e.g., from the atmosphere during the past 8000 years.

c. The sample has maintained its original carbon content without exchange with its environment during burial.

d. The level of contamination is weak to moderate and can be removed by mechanical and chemical pretreatment.

e. The condition of the sample is sufficiently robust to allow a thorough pretreatment.

f. Sample size is sufficient for dating at the required level of precision, e.g., 3g carbon for a conventional date with 0.3 to 1% precision and 5mg for AMS dating with 1 to 2% precision.

Conditions c, d, and e are in part controlled by man made environmental changes such as the ones studied in the present workshop.

4. In North America the range of the age dates which is of greatest interest to archaeologists is about 100 years to 13,000 years B.P (before present). In the following chapter, the characteristics of the most frequently processed carbonaceous sample materials are discussed.

Characteristics of Frequently Analyzed Carbon Sample Materials

Charcoal

5. Occurrence. In situ occurrences are in hearth and post holes. Frequently charcoal is recovered from scattered deposits, such as on living floors and in middens. Often it is found dispersed throughout a site with no traceable connection to a particular source.

6. Significance. Charcoal is by far the most preferred sample material. Charred seeds, nuts and reeds have a close association with past human presence since their growth occurred within a short time span, usually one year or less, from the activity at the site. Most other types of sample materials have disadvantages which are not found in good charcoal samples.

7. Quality. The chance of survival of a charcoal sample in adverse environmental conditions is strongly dependent on the type of wood that was burnt and on the degree of charring of the wood. Hardwood and nut shells yield dense and robust pieces of charcoal which will withstand mechanical burial and compaction of the soil strata.

8. In an ideal situation, the recovered charcoal samples have undergone the full charring process which, at high temperature and under exclusion of oxygen, transforms all organic compounds of the wood to an inorganic structure containing mostly carbon. The majority of samples, however, are only partially charred, with a substantial part of the sample remaining as altered organic compounds. The latter are subject to weathering and decay. This process leads to a darkening of the sample, making the visual distinction from fully charred samples very difficult. The decay products are similar to humic acids and are thus readily mobilized by alkaline solutions.

9. This process occurs rapidly in a weakly alkaline environment. In the laboratory a 0.01% NaOH solution with a pH of approximately 10 will dissolve a decaying charred piece

of wood, which has an otherwise solid visual appearance, in just a few hours. It must therefore be assumed that a change in soil chemistry from a weakly acidic to a weakly alkaline soil will have a substantial impact on the preservation of one of the most important sample materials.

10. Preservation. At shallow depth protection from mechanical impact is most important. Charcoal is likely to be destroyed at shallow depth in an agricultural area (plow zone), leaving hardly an observable trace. Other adverse activities are off-road vehicular traffic, burrowing animals and roots from vegetation. The chemical properties of the soil are less important as long as the sample has originally been well charred.

11. Other adverse effects on preservation are caused by abundant root growth which easily penetrates charcoal pieces. Groundwater and high soil moisture support transportation of dissolved organic compounds from decaying vegetation. Most organics are readily absorbed by charcoal, just as they are during the utilization of charcoal for filtration and purification of gasses and liquids. In the same way charcoal will absorb organics carried by runoff from roads and parking facilities where oils, refuse and litter accumulate, and from intense animal activity as it occurs on feed lots and during heavy grazing.

Wood

12. Occurrence. Most useful wood samples are related to former dwellings. Post holes may still contain some of the original wood. In arid climates wood is often preserved in above ground locations, such as pueblo ruins. Stratigraphic studies may benefit from the discovery of a buried log in an ancient stream channel or lake bed, but such associations may be questionable because the log may have originated from a distant location and possibly was deposited, remobilized and transported again several times.

13. Significance. Wood samples with reliable association and good state of preservation are rare. If they are found, an attempt should be made to date the sample by matching the tree ring pattern against a known chronology which is valid for the region.

14. Quality. Wood which has been buried in anaerobic condition is quite stable, if left undisturbed (Spiker and Hatcher 1987). Arid conditions at or near the surface are required for preservation up to 1000 years. Further preservation is limited by the splitting and mechanical deterioration of the sample, leaving small pieces which are easily dispersed.

15. Samples which were reasonably well preserved under the above conditions can usually be pretreated for removal of all contaminants and therefore yield reliable age dates. Somewhat less reliable dates are obtained from wood samples which were recovered from moist soil strata. Usually much of the wood has decayed to humins.

Pretreatment breaks the crumbly wood down into a pulp of fine fibres. Post hole samples often fall into this category.

16. Preservation. Wood is well preserved in clayey soil strata (ancient lake beds) with an acidic pH or in well drained sandy soils in the arid regions of the southwest. Wood is poorly preserved in humid conditions or over wet/dry cycles. Shallow burial near cultivated surfaces is very unfavorable because of root growth and penetration by humic acids. Soil bacteria and mold accelerate decay. Such conditions could be found at public park land.

Bone

17. Occurrence. Archaeologically most important are human burials. However, animal bones are found more frequently and usually can be sacrificed for dating. They are found in direct association at butchering and camp sites, in habitation areas where food processing took place, in middens and refuse piles and at ceremonial sites. Other occurrences are in ancient ponds and river channels where animals were trapped in the soft bottom sediments.

18. Significance. It is highly desirable to obtain reliable dates from bones since the association with human activity is usually very good. However, bone is often an unreliable sample material because preservation is poor and analytical procedures are lacking the necessary sophistication. There are, however, conditions under which good dates can be obtained.

19. Quality. Well preserved bone consists of hydroxyapatite, the phosphate mineral of the hard fraction, and the collagen organic fraction. Both fractions can be used for dating, whereby collagen is chosen more frequently. It is recovered in the laboratory from an acidic solution in which the mineral part of the bone had previously been dissolved. The rubbery collagen particles can be purified by extracting humic acids which accumulated during burial. Pretreatment procedures also remove algae, fungi, rootlets, etc AMS dating has made possible the dating of individual amino acids extracted selectively from the collagen. (Stafford, Brendal and Duhamel 1986, Taylor 1980, Gillespie, Hedges and Humm 1986). This technique is new and still experimental and no laboratory offers it for routine applications. Early results indicate that the method is reliable, but the projected high cost will restrict it use to few applications.

20. Apatite dating is only attractive when the organic fraction has not been preserved and an approximate date is urgently needed. Separation of secondary mineral deposits from the bone mineral fraction is difficult and most of the time incomplete (Haynes 1968, Hassan 1976, Hassan and Ortner 1977). The standard dating technique consists of collecting CO_2 gas from the acid hydrolization of the bone sample. A more

advanced and reliable technique uses the thermal breakdown of the bone minerals (Haas and Banewicz 1980). Again, this method is only practiced in research oriented laboratories. Large bone samples are required and the cost is high.

21. Preservation. The preservation of bone is most ideal in an environment which is slightly moist, alkaline and cool year round. For this reason the best preserved bone is found in northern Canada and in Alaska. The positive correlation between temperature and decay of bone collagen has been studied by Ortner, Von Endt and Robison (1972). Their laboratory studies indicate that the organic fraction of bone should be completely degraded within 7500 years in climates typically found in the region of the middle latitude states of the U.S. (Figure 1). In reality, preservation is somewhat better. At the Hudson - Meng Site in Nebraska bone was recovered which could be dated at 9400 BP. The estimated true age is 10,000 BP.

22. The strong correlation between soil pH and preservation of buried bones has been demonstrated at the two sites near the Illinois and Mississippi Rivers (Gordon and Buikstra 1981). A prediction of the preservation state is possible from the soil analyses.

23. Adverse conditions for preservation exist in hot and cyclical (wet and dry) conditions. Surface exposure represents an equally unfavorable situation which leads to complete breakdown of bone within a few years. Burial at the depth of a fluctuating ground water table leads to leaching of the collagen. Below the water table, movement leads to the deposition of clay and silt in the bone tissue and to the formation of secondary carbonate minerals, all of which are difficult to remove (Hassan 1977).

24. Burial at shallow depth exposes the bone to contamination by vegetation and its decay products, i.e., roots, fulvic and humic acids.

Shells

25. Occurrence. The term shell refers here to the protective carbonate "housing" of different phyla of invertebrate animals. Shells from pelecipods (clams) and from gastropods (snails) are the two major groups, whereby snails are divided into aquatic and terrestrial habitats. Each group requires a different approach for the age calculations which are made from raw radiocarbon counting data.

26. Clam shells are found dispersed in refuse piles near settlements or in piles near temporary food gathering camps. They are found as natural accumulations along ancient and buried stream channels, beaches and sea shores. Archaeologically important occurrences of snail shells are not abundant in North America. Snail shells were used occasionally as ornaments. However, snails have not been part of the diet of North American man. Therefore these shells are very seldom found here in dateable quantity. The exceptions are natural assemblages found in association with former water bodies.

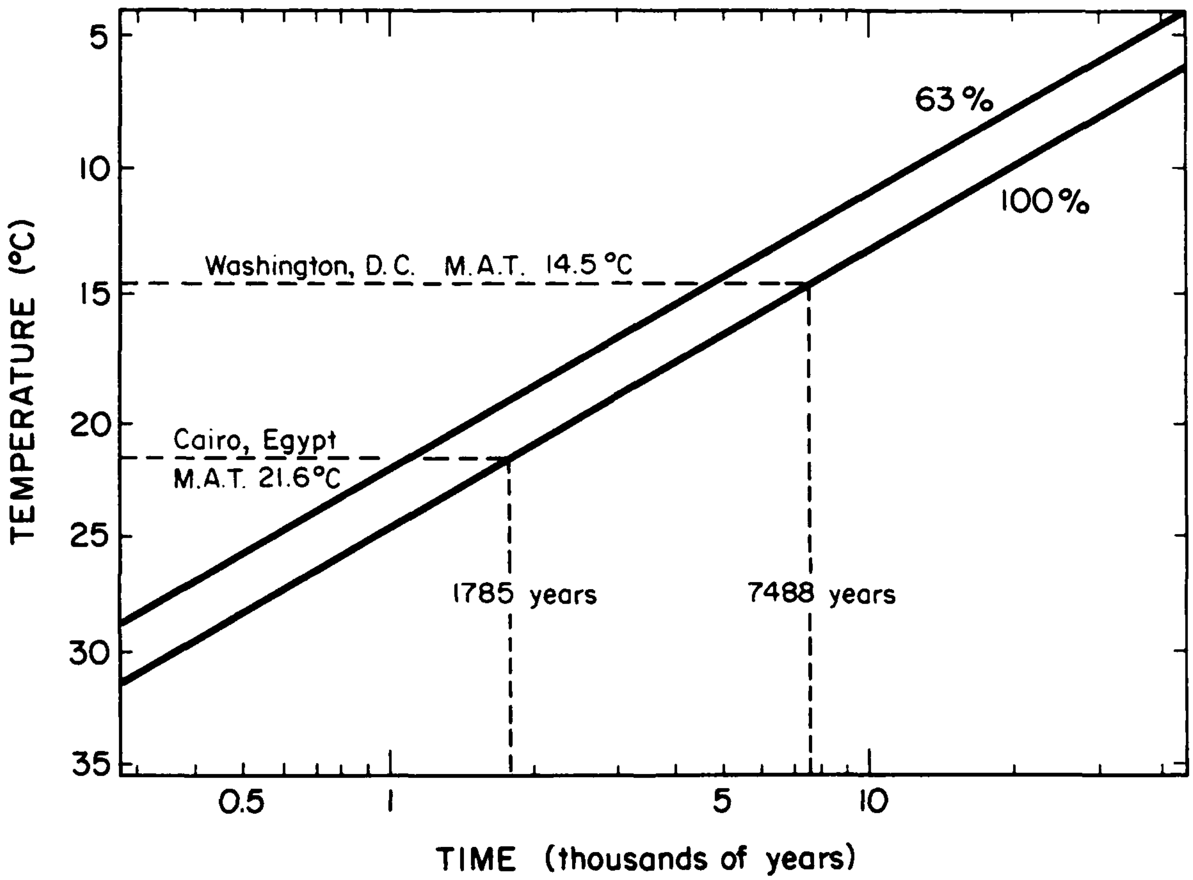

Figure 1. The effect of temperature on nitrogen release from bone. The vertical cooordinate indicates the temperature in a range found at most archaeological sites. The horizontal coordinate indicates time in thousands of years. The 63% and 100% lines show the number of years it takes for bone to lose 63% and 100% of its nitrogen at temperatures from approximately 5°C to 31°C. The dotted lines show how many years it would take all the nitrogen to disappear from bone at the mean annual temperatures of Washington, D.C., and Cairo, Egypt (modified from Ortner, Von Endt, and Robinson 1972).

27. Significance. Since one of the major conditions for reliable dating results is not fulfilled with shells, namely the origin from a carbon reservoir of known C-14 concentration, shells are only used when no other materials are available. Streams, lakes and ponds all have different and temporally varying C-14 concentrations, which are reflected in the initial C-14 content of the shells which grew there. Terrestrial species of snails are more closely tied to the atmospheric carbon isotope ratio which is much less variable. However, these shells are usually small and very difficult to clean from secondary fillings. As a result, the majority of shell dates are suspect.

28. Quality. The true state of preservation is difficult to evaluate. Shells with a fresh appearance can be mineralogically altered and as a result the carbon isotope ratio has been changed (Yates 1986). This alteration, or recrystallization, is a slow solid state process which is accelerated by a rise in temperatures and by the presence of soil moisture. The latter helps in the ion transport and ion exchange between the shell and other carbon sources in the soil. Heavily altered shells can be recognized by their chalky appearance. Clams also will split readily parallel to their outer surfaces, producing small, curved flakes. Heavy walled shells may have a "core" of unaltered material. A large sample (100g or more) often makes possible an adequate preparation by filing and acid etching.

29. Preservation. An ideal environment is a dry, impermeable, clayey soil with an alkaline pH. Adverse conditions are humid soils with acidic pH which leads to rapid degradation and dissolution of the shell material. Surface exposure and wet/dry cycles are also unfavorable for preservation.

Organic content of soils

30. Definition and occurrence. The base soluble organic fraction of soils or sediments is referred to as the humate or humic acid content. It consists of large molecules with molecular weights above 10,000 and is, as a compound, hard to define. These molecules adhere to clay and silt size particles and originate from decaying vegetation, especially on the soil surface from leaf litter and dead grasses. In the top soil layer, dead roots and surface vegetation buried by rodents both contribute to the humate content. Soil fauna, like worms and beetles, provide another source.

31. Of primary interest for dating are humate concentrations in A-horizons of recent and of buried soils. Lower concentrations occur in B-horizons, ancient pond and lake sediments and soils from arid regions. In charcoal, wood, and bone, humates represent a frequent and often significant contaminant.

32. Significance. Humates are the least likely material to be used for accurate dating since they originate from a gradual process and are subject to local mixing. Therefore no detailed and precise chronology of a soil profile can be expected (Gilet-Blein,

Marien, and Evin 1980). A few studies have been made (Scharpenseel 1972, Scharpenseel 1979, Sheppard, Syed, and Mehringer 1979, Fowler, Gillespie, and Hedges, 1986, Haas, Holliday, and Stuckenrath, 1986) which demonstrate a good potential for establishing relative chronologies. Under ideal conditions, reliable absolute chronologies are possible as demonstrated by the Lubbock Lake Site (Haas, Holliday and Stuckenrath, 1986).

33. Quality. The usefulness of humic acids is limited by their mobility in the ground. Since they are by definition base soluble, humates will be leached from an alkaline soil, leaving it without a datable organic content. The humic acids may, after transport into a soil with lower pH, floculate and remain fixed at a chronologically unrelated location. Groundwater and its movement are also very important factors in the mobility and preservation of humates. Extraction and purification of humates from clay rich soils technically can be very difficult. Coarse, sandy soils usually contain low concentrations of humic acids and therefore cannot be dated.

34. Most soils contain a non-soluble organic content, which consists of cellulose fibres and other matter with cellular structure. It is often called residue or humin fraction of the soil. It can be dated by combusting the bulk of the soil after its humate fraction has been extracted and all carbonate minerals were removed by acid digestion.

35. Preservation. Numerous tests that were made at a variety of locations indicate a good preservation of the organic content in acidic soil of low porosity in the unsaturated zone. Adverse effects must be expected with a rising or fluctuating water table. Warm temperatures, moisture and high porosity are conditions leading to oxidation and loss of soil organics. Open trenches also will lead to this form of degradation.

36. Natural and man made sources of contamination are numerous. Major sources are oils from road and parking lots, some agricultural chemicals, animal wastes and replacement or addition of top soil. Contaminated humic acids cannot be purified with standard laboratory techniques.

37. Figure 2 (A and B) summarizes the individual discussions of those radiocarbon sample materials which are most likely found in an archaeological excavation. With the exception of wood from structures situated in an arid environment, all of these sample materials require burial and a below surface resting place for good preservation. Two variables are considered in the diagrams: acidity or alkalinity of the soil, and moisture of the site.

Other Dating Techniques

38. The six dating techniques described below have also been evaluated in

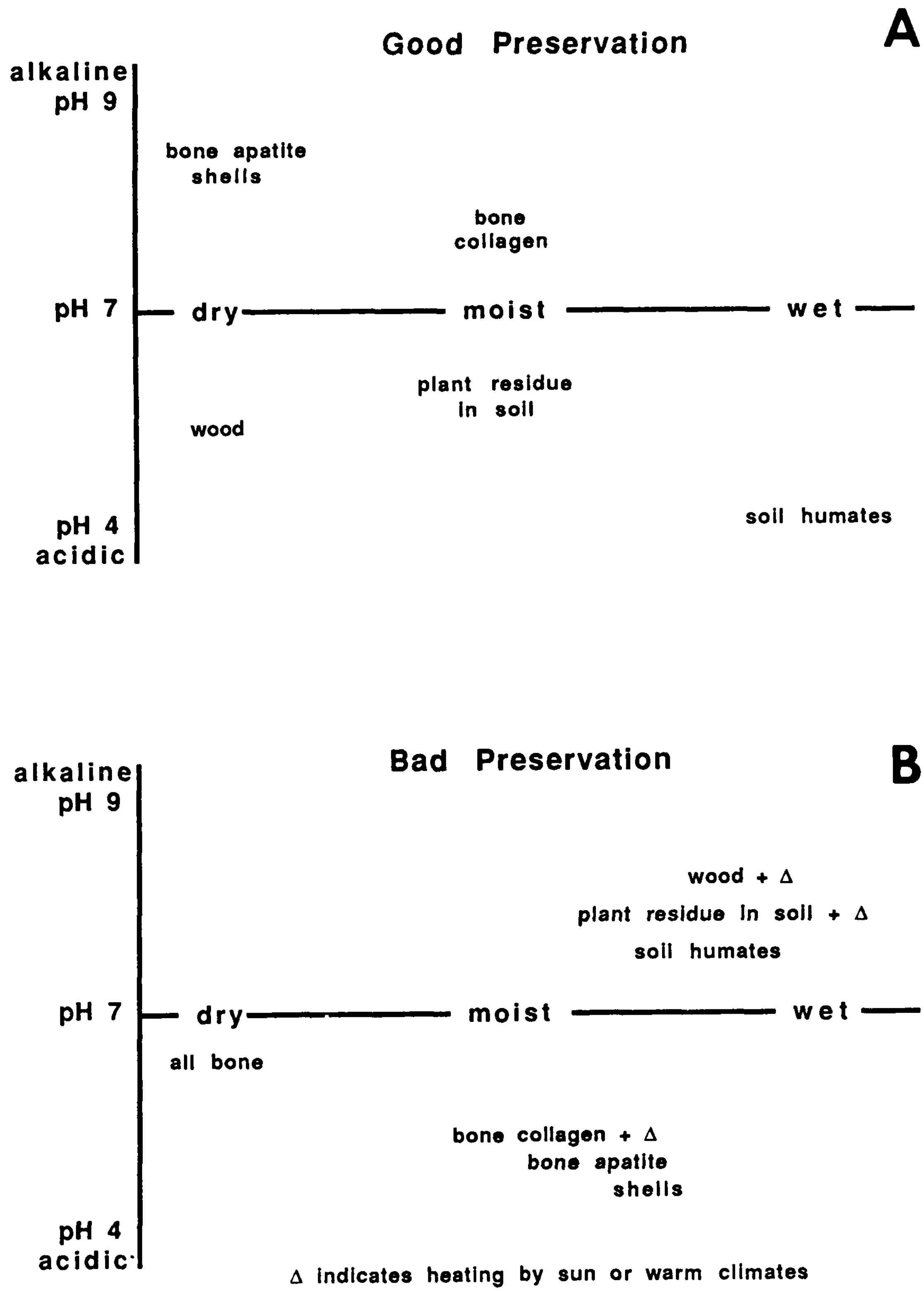

Figure 2. Diagram A shows the ideal conditions which lead to good preservation. Diagram B presents the conditions which lead to decompositon of the sample material.

connection with the National Reservoir Inundation Study (Lenihan et al. 1981). The brief summaries offered here are based on theoretical considerations, whereas conclusions in the Inundation Study are based on measurements made on field samples. Both studies result in the same recommendations, namely that submergence is detrimental to most of these dating methods.

Thermoluminescence dating

39. Pieces of pottery or baked clay lumps around hearths are continuously exposed to a weak flux of nuclear radiation emitted by radioactive impurities in these objects and in the surrounding soil. When heated rapidly, the powderized samples will emit a small amount of light, which represents stored radioactive energy and which is proportional to the length of time the sample has been irradiated in its resting place (Aitken 1985). The measurement of the light allows an estimation of the age of the object. Disturbance through leaching of the radioactive elements or through heating of the sample in direct sunshine or in a hot surface layer of soil will weaken the particular atomic properties needed for application of this dating method. Thus earth moving activity or changes in the ground water table can have adverse effects.

Fission track or alpha-recoil track dating

40. This dating method also makes use of the observable effects of natural nuclear radiation on artifacts. The fission or the alpha decay of heavy radioactive elements causes, through recoil of the daughter particles, a tunnel like path of damage inside the host mineral. These damage spots are called fission tracks and can be made visible. Their number is proportional to time and to concentration of fissile elements. Counting the tracks and measuring the amount of uranium leads to a computation of the age. Mica minerals are particularly well suited for track counting but they are unstable in saturated groundwater zones. Weathering of the uranium containing minerals destroys the record. Frequently examined minerals are the micas which are not stable in saturated ground water zones. Groundwater will also affect the uranium content by slowly leaching it from the samples.

Uranium-Thorium dating

41. Uranium-thorium dating involves the measurement of accumulating daughter products on the decay chain of uranium isotopes. Only dense organic tissue is suitable for this dating method, e.g. the enamel of teeth. The previous discussion on the preservation of bone is also applicable here, whereby the additional concern of leaching the uranium and thorium isotopes through increased moisture in the soil must be considered.

Hydration of obsidian and chert

42. Several studies have been made on the linear progress of hydration on fresh

obsidian surfaces (Lenihan et al. 1981). Over short periods of time there seems to be no measurable change in the hydration rate of obsidian with a change of the moisture content of the host soil. It is important to note that most published studies apply to obsidian but do not include flint, a much more common raw material for stone tools. Flint has different hydration characteristics and the independence of its hydration rate from surrounding moisture has not been established.

Archaeomagnetic dating

43. Minerals with the property of maintaining a magnetic field lose this property when heated but gain a new magnetic field when cooled again. The new field will be oriented parallel to the local earth magnetic field, which has varied over time. If the local chronology of the earth's field is known, the field direction and intensity of suitable archaeologic samples can be measured in the laboratory and compared to the time variation of the earth's field. It is important that the sample has undergone the heating and cooling cycle during a human activity of interest to archaeology such as firing a pot or a hearth fire. Weathering of the samples will affect the magnetic properties. Thus any change in the burial environment which increases the weathering of minerals or introduces oxidizing conditions to the soil strata will adversely affect archaeometric dating.

Bone dating with amino acid racemization

44. This technique proposed by Bada and Protsch (1973) is based on the change over time of the structure of aspartic acid, a component of bone collagen. The proportion of changed and unchanged materials is a direct measure of time (Bada and Helfman 1975). The rate of structural change of aspartic acid is also strongly dependent on temperature and somewhat on the moisture content of the surroundings. These latter variables are seldom known exactly for the past. Dating results based on this method have therefore been unsatisfactory. Research on the method and other related dating techniques is still in progress. In considering preservation for future analyses, these techniques must therefore be included in all conclusions.

Expected Changes and Effects on Archaeologic Materials During Burial or Inundation

45. This chapter summarizes the discussions of different sample materials and dating techniques.

Burial

46. The exact procedure of burial will determine the degree of preservation or degradation of archaeological material. Ground surface preparation by scraping, deposition of an impermeable clay layer, the nature of the soil used as overburden and the

final surface on top of the overburden all influence the outcome of the preservation effort.

47. Temporary impact during the burial procedure could result from mechanical compression by heavy equipment, destroying charcoal and fragile bones and shells.

48. Removal of the top soil prior to burial will result in the exposure of lower soil layers to heating by the sun's radiation. This reduces the potential usefulness of future thermoluminescence dating and possibly also for bone dating. Only a brief episode of heating causes irreversible changes in the thermoluminescence of minerals and in the collagen structure of bones. Future racemization dating would certainly be eliminated by even moderate temperature changes.

49. Changes in the soil chemistry, mainly the acidity or alkalinity of the soil, will affect various sample materials in different and some times opposite ways. A more alkaline pH adversely affects wood, some charcoals and the humic acid content of soils but may help in the preservation of bone. A more acidic pH leads to the degrading of the shells and bone, but wood is better preserved in this environment.

Inundation

50. In the preceding discussions on sample types and alternate dating techniques, a common conclusion is that increased soil moisture, or submergence below the groundwater table will be detrimental to future, archaeometric measurements. For radiocarbon dating, partial loss of sample material without change of the carbon isotope ratio will probably not preclude age measurements because the AMS technique should allow dating of very small remnants of the sample. AMS results will have the same accuracy as conventional dates, but will suffer from decreased precision. At the same time, increased costs and possibly longer waiting time for results must be accepted. A degradation of the sample material accompanied by carbon exchange and by carbon isotope fractionation is more probable. A loss of accuracy must be expected in this case.

Opportunity to Measure Impact of Inundation on an Existing Archaeological Site

51. The final report of the National Reservoir Inundation Study (Lenihan et al., 1981) presents results of laboratory studies and field tests of various archaeologic materials and sample types. Conclusions offered are valid and corroborate the observations made by radiocarbon laboratories. The study is incomplete in the sense that it does not cover all sample materials. Bone collagen preservation, carbon isotope changes in shells and organics in soils are not at all or only briefly covered in the study.

52. An excellent opportunity to fill some of these gaps in knowledge exists at the

Lubbock Lake Archaeological Site. Lubbock Lake has excellent age-control for all principal strata, soils, and cultural features. This age-control is provided primarily by about 120 radiocarbon dates (see Holliday 1983; Holliday et al. 1985, Haas, Holliday, and Stuckenratn 1986). Cross checking of dates is possible because of the excellent stratigraphic record ,the abundant archaeological materials, and the variety of materials that were dated.

53. Beginning in about 1980, portions of the reservoir area at the site became inundated by a slowly rising water table which intersected the reservoir. Today the floor of the reservoir is covered by water which locally is up to 3m deep. The water covers strata 1 and 2 and parts of 3. Most of stratum 3 and locally parts of stratum 4 are also kept damp. The water in the reservoir contains abundant organic material from plants and animals that live and die there.

54. The best dating record from the site is in stratum 2, with most dates determined on humates and residue. Stratum 2 also has a rich Paleoindian archaeological record. This situation affords the possibility of studying the effects of saturation by waters rich in organic debris on humate and residue dates. If the reservoir can be drained and kept dry (requiring continuous pumping of the ground water at the reservoir to keep the water table well below the floor) a sampling strategy can be designed to collect materials from well-dated areas for re-dating. This should include dating the humates as well as residue and perhaps other fractions. Dating could also be attempted on water saturated bone and perhaps other materials such as shell and charcoal if any are found.

Outlook into the Future and Proposed Experimental Methods for Evaluation of the Consequences of In Situ Burial and Inundation

55. In the preceding chapters, many practical and well-established methods used in archaeometry have been presented. Undoubtedly future advances in analytical methods will lead to new dating techniques; e.g. electron spin resonance (ESR) has the capability to determine the nature of chemical bonds inside complex molecules. It is possible that strongly time-dependent changes occur in large organic molecules which, when discovered, will provide us with a new clock. Today we do not know conditions for preservation of such potential future sample materials. The best approach therefore is to avoid chemical, mineralogical and mechanical changes in the soil. Preservation efforts involving soil stabilizers, vegetation control through spraying, drainage control by mechanical means should all be avoided in order to not accelerate the unavoidable natural changes. If this cannot be done in situ, a new storage environment must be made available for small but

representative parts of the sites. This means recovery of archaeometric sample materials prior to major changes in the environment of sites.

56. For this purpose, we propose that every site with the potential for containing important archaeologic information be subjected to a standardized test sampling and be fitted with an experimental "time capsule." The sampling should include surface features, such as hearth rocks, lithics and pottery. Subsurface tests by augering or small, shallow trenches will add soil samples and may also yield charcoal, bone and wood. All of these materials must be stored off the site in a dust-free, dry and cool environment.

57. At the same time, a "time capsule" should be added to the site for the following reasons: future research at the preserved site can be supported by providing test materials which will undergo the same environmental changes and exposures as the archaeological features left in the site. These test materials should include standardized materials of the same kind as samples which might be found during a future reexcavation of the site. Likely test materials are fresh bone, wood and charcoal, nuts and seeds, shells, flakes of flint or obsidian, ceramics made from different raw materials and temper and with varying firing techniques. These materials are to be deposited in a test trench or an auger hole at the depth of the major cultural zone and surrounded with the original soil or sediment. Later rediscovery of the burial spot must be assured with a survey which includes permanent features in the landscape. A marker of rocks or inert metal alloy will also help in finding the exact placement of the test materials. Duplicates of the standardized test materials and their exact descriptions should be deposited at a state or national facility such as a State Archaeological Survey or the Smithsonian Institution.

58. At the time of the reexcavation of the site, the condition of the recovered "time capsule" will allow assessment of the impact of burial or inundation to the preservation of the site and its features. The conclusions can be applied to the research on recovered archaeological sample materials. This will facilitate the measuring and description of the original biological, chemical and mineralogical composition of artifacts, and also improve the accuracy of other tests such as age dating.

59. As a final benefit, our knowledge of the impact of site preservation techniques will be enhanced by numerous opportunities to observe and measure precisely the level of decay which was imposed artificially.

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CLIMATOLOGY

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Introduction

1. The atmosphere plays a major role in the weathering and decay of all items exposed to its impacts and, indirectly, to those covered by soil and other materials. There are two aspects of the atmospheric conditions that contribute to the deterioration of the item, namely: 1) the mean level of a particular element of the atmosphere, such as temperature, radiation and precipitation; and 2) the variability of the element, i.e., its fluctuation over many time scales. Therefore we must be concerned with knowing the average state of the atmosphere and its possible (or identified) fluctuations. To assist in interdisciplinary communication, it is necessary to clarify the meaning of some important terms. These are presented in Table 1.

Causes of Climate and Weather

2. If we are to understand the atmosphere and its variations, it is essential to be aware of the primary and secondary controls, or causes, that lead to the effect we refer to as climate or weather. The five primary controls are: 1) radiation balance; 2) interface; 3) Earth's rotation; 4) land-sea configuration; and 5) global topography. It is seen that the first two of these are extremely variable in time and space, while the three remaining are constant, to all intents and purposes, unless we are considering time scales of the order of millions of years.

3. Unfortunately, we cannot just insert values for these five factors into gigantic mathematical-physical equations and get a supercomputer to predict the weather/climate for us. The approach is purely qualitative, not quantitative. Because of this fact, we need to introduce secondary factors: 1) atmospheric pressure; 2) air flow; 3) ocean circulation; and 4) air masses. These are ones that stem from the primary factors but, because they are measurable or readily identifiable, can be more easily linked to the resultant weather and climate.

4. A natural aspect of climate/weather is its variability. The average (or normal if

Table 1

Definitions

* Climate - The synthesis of weather; or
The state of the atmosphere during a period of time.

* Climatography - A description of the climate.

Climatic factor (or control) - A determining cause of the climate, such as solar radiation, earth-sun geometry, land-sea configuration topography, etc.

Climatic elements - Component parts of the climatic system, such as temperature, precipitation, wind speed, dewpoint, etc.

Climatic variables - Aspects of a climatic element; for temperature these could include heating degree-days, number of days exceeding 90^{o}F, length of frost-free period, etc.

Climatic variation

1. Climatic revolution: over 10^6 years.
2. Climatic change: 10^4 to 10^6 years.
3. Climatic fluctuation: 10^1 to 10^3 years.
4. Climatic iteration: less than 10 years.

* Should include information not only concerning average conditions but also the variability and frequency distributions of the climatic variates.

specific 30 year records are used) is often a relatively rare event. For example, to have all 12 months in a year recording within 10% of their respective means would be very unusual. To illustrate this, let us assume a chosen variable for each month has a standard deviation equal to 20% of the mean and that the distributions all exhibit the Normal or Gaussian pattern. Then, monthly values occur within 10% of the mean about 40% of the time; so the chance of getting a year with 12 such occurrences is $(0.4)^{12}$, or about 0.000016; 16 chances in a million! Therefore model building must include the reality of variability.

Climate Variation

5. What do we mean by climate variation? A pattern of rainfall may be regarded as highly variable by a grass with shallow roots, while to a tree with long roots, it would be considered uniform. In other words, the two plants have different concepts of "memory." A most fascinating paper by Curry (1962), entitled "Climate Change as a Random Series" illustrates, among many facets, that if a tree requires certain specific conditions to exist during each of five consecutive years, conditions that have only a 0.01 probability of occurrence in a year, then there is still a 10% chance of there being a recurrence interval that would allow the successful establishment of a reproducing forest.

6. It must be realized that the impact of a climatic variation depends on two features - the degree of change and the size of the region affected. In this way it is somewhat similar to drought. However, drought is often defined so as to address the variation in a single climatic element, precipitation, whereas climatic change can, and often does, infer fluctuations in many elements. It must be noted that very often a published article will be entitled "climate change" and yet will address only a single element, such as temperature or air flow patterns.

7. For illustration, let us consider two examples, the Little Ice Age and drought, so as to understand the complexity of the problem. The Little Ice Age is a term often applied to a period during the past 800 years during which a region, generally in Asia, Europe or North America, experienced a large percentage of years with cool summers and/or severe winters. In eastern Asia this apparently occurred around 1200 to 1500 A.D., in eastern Europe from 1350 to 1700 A.D., and in western Europe around 1500 to 1850 A.D. These are significant time shifts that are difficult to explain, especially since a warm dry regime happened in 1680 to 1700 A.D. in western Siberia, a time coincident with the coldest phase of the Little Ice Age in western Europe. The variations in precipitation were apparently not as easily categorized during this period.

8. Droughts, defined here as prolonged periods of below average precipitation,

affect all areas at some time. Even the Amazon basin can experience a drought but, because of its general abundance of water, its overall impact would be less than for a drought occurrence in, say, the Texas Panhandle. Much attention has been given to droughts, how to define them, and determine their intensity, duration and areal extent. Cycles in the occurrence of droughts have been postulated, such as a 22-year periodicity in the Great Plains. This can be misleading, as the analyses may suggest periodic patterns in the likelihood of droughts in the area but does not infer a particular site experiences such a pattern.

9. Droughts have been related to sunspot cycles, but a glance at Figure 1 will dispel any ideas of a simple relationship with drought incidence. As with many atmospheric phenomena, there is only limited synchronicity, as is well shown in Figure 2.

Climatic Elements and the Decay of Sites

10. The basic climatic/weather elements that can have an effect on the decay of archaeological sites are: solar radiation; temperature; atmospheric humidity; air flow; precipitation. See Table 2 for a summary of their impacts.

11. Although it is realized that, when dealing with a specific site, we are concerned with variations of climate on the micro-scale, nevertheless the macro- and meso-scale climates also play fundamental roles. Therefore it is necessary to consider variations in the atmospheric conditions occurring not only on various area scales but also on all time scales from tens and hundreds of thousands of years (in earth/sun geometry) to a few hours (a local flood situation).

12. Any site begins to change (decay) immediately after its abandonment. Sites that come to light after hundreds or thousands of years (whether exposed or covered) have suffered change during that time. Since the emphasis of this Workshop is on the covering of sites by drowning or burying, I will, in the interests of time limitations, address only this situation. The problems of sites freely exposed to the atmosphere can be considered in the discussions, if deemed necessary.

13. With regard to drowned sites, these effectively are removed from the atmospheric influence, except in as much as (1) precipitation run-off can bring chemicals into the inundated region, and (2) if the covering is shallow, air flow can cause wave actions that may be deleterious. An additional scenario is if the water flooding the site is subject to a freeze-thaw cycle, a situation that is not desirable. When the site is buried then, as mentioned earlier, the atmospheric impact generally is cushioned. However, there are exceptions to this concept. For example, if a site is close to a major conurbation, then

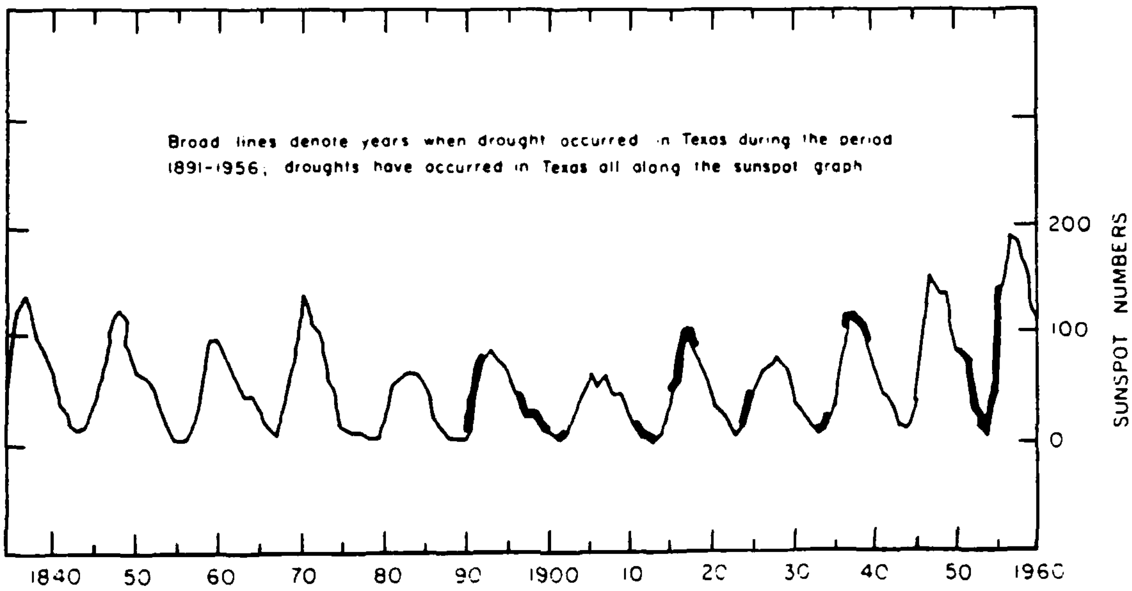

Figure 1. Sunspot graph with drought years in Texas (Carr 1966).

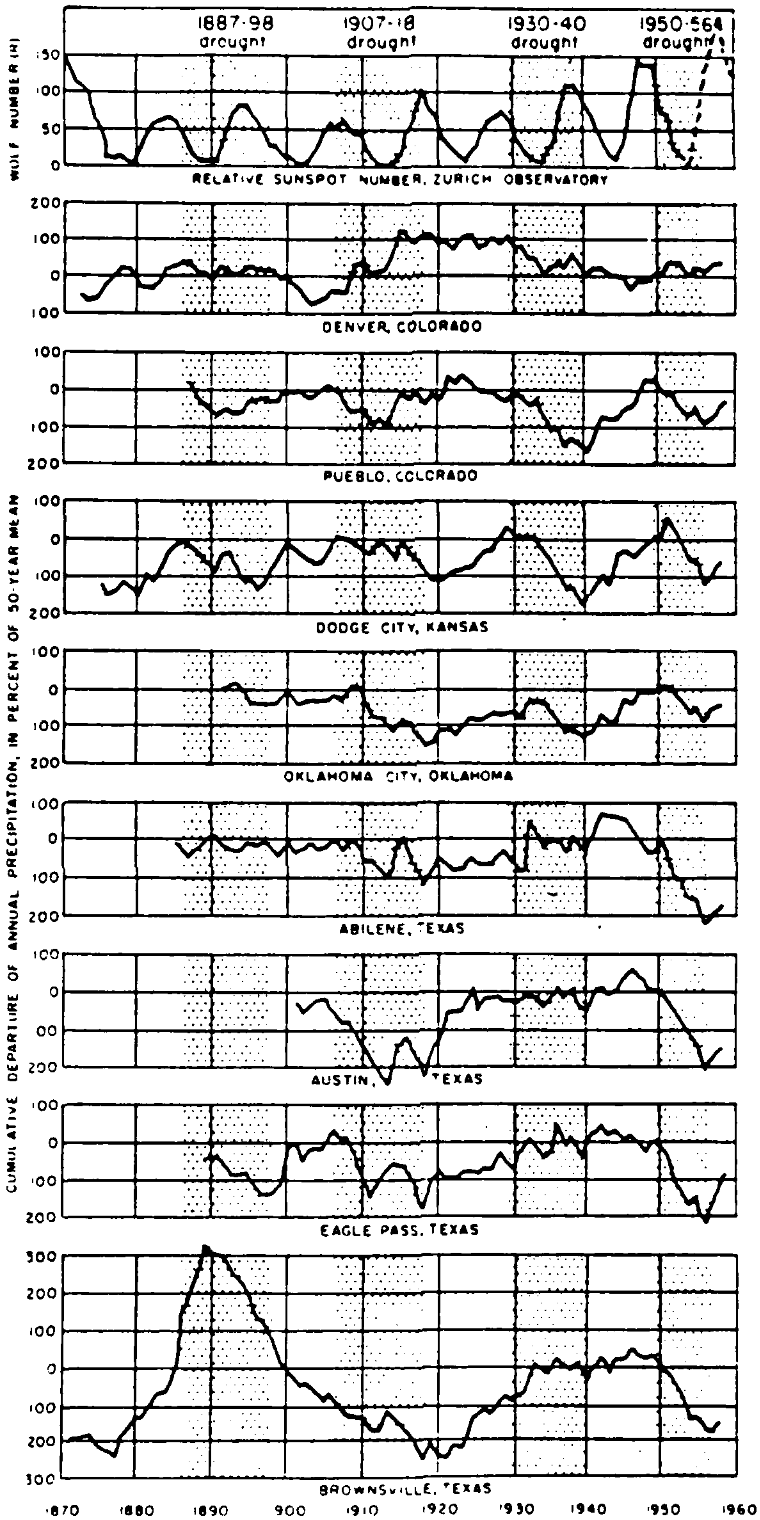

Figure 2. Fluctuations of annual precipitation at eight cities in the Great Plains zones (Carr 1966).

Table 2

<u>Climatic Elements and Their Effects</u>

<u>on the Decay of Archaeological Sites</u>

<u>Solar radiation</u>

Covered sites - negligible,
Exposed sites - high values lead to expansion problems; in conjunction with high temperatures the impact is magnified.

<u>Temperature</u>

Covered sites - daily and seasonal ranges reduced to practical insignificance,
Exposed sites - relationship with radiation and humidity important

<u>Atmospheric humidity</u>

Covered sites - small effect, dominated by soil moisture,
Exposed sites - in conjunction with temperature can lead to problems.

<u>Air flow</u>

Covered sites - high speed and gustiness lead to erosion, magnified for dry soil,
Exposed sites - scouring and weathering with high speeds.

<u>Precipitation</u>

Covered sites - effects are through soil moisture and soil erosion (floods),
Exposed sites - physical damage by impact.

rainfall and temperature amount and patterns could be changed, the former quite significantly, and a problem with acid rain could arise as this is washed into the soil. In addition, urbanization causes drastic alterations to run-off patterns by the removal of trees and other plants, the concreting of large areas and the cementing of stream and river banks.

14. If a site is buried, it is useful to have some knowledge of the temperature and moisture conditions likely to exist in the soil. Temperature patterns are much more regular in soil than in the air and some reasonable generalizations can be made. The rate at which heat penetrates into the soil and the time taken are both related to the thermal diffusivity. This physical characteristic is simply the product of the heat capacity and thermal conductivity. The diffusivity rises with increasing moisture content, then decreases, the maximum values being from about 10 to 30% moisture content, depending upon the soil. The diffusivity increases as a soil is compacted, while the introduction of organic matter decreases it. For most soils, the value lies between 0.01 and 0.001 cm/sec, with an average of around 0.004 in soils of the moist temperate regions. The greater the diffusivity, the smaller is the amplitude of the temperature variation while the more rapid is the speed of propagation of the temperature wave.

15. In order to give an idea of the thermal patterns under various conditions, some examples will be shown. In Figure 3 temperatures are shown for the surface and depth of 2 in. (5 cm) in four types of soil: clay, peat, loam and sand (these are in increasing order of particle size). It is clear that at night and for part of the day, temperatures may vary less than 5°F (3°C) among the different types, but around noon or early afternoon, considerable differences are recorded. However, these diminish rapidly with depth from a range of about 32°F (0°C) at the surface to 14°F (-10°C) at 2 in. (5 cm).

16. Figure 4 shows a similar pattern but extends to a depth of around 32 in. (0.8 m). It illustrates also how mean temperature tends to increase with depth in the cold season. Figure 5 introduces the annual temperature variation with depth. It shows the reduction of annual fluctuation and the lag with depth from one level to the next. At 25 ft (7.5 m) there is very little annual change and winter is the warmest season. This compares with a depth of about 1 ft (30 cm) in an average soil, at which the diurnal cycle is usually unimportant and the highest temperature is noted around midnight.

17. Soil moisture presents a more complicated picture than does temperature because changes in this can occur very rapidly. The atmospheric element involved is, of course, precipitation and soils can show marked variation in moisture during the year in the zone of aeration (above the water table) if there is an appreciable seasonal change in precipitation amounts. A cycle of wetting and drying could be very destructive to some

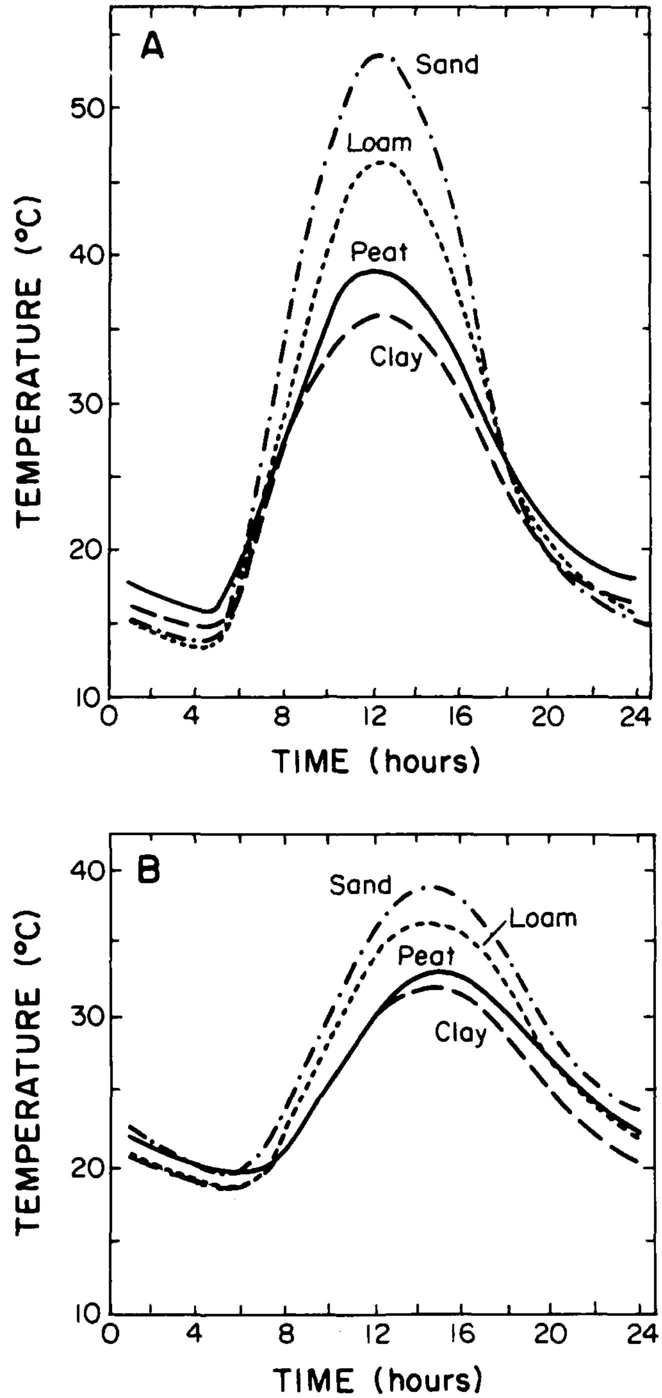

Figure 3. Daily course of temperature (A) at the surface (B) at a depth of 50 mm on clear summer days at Sapporo, Japan (modified from Chang 1968).

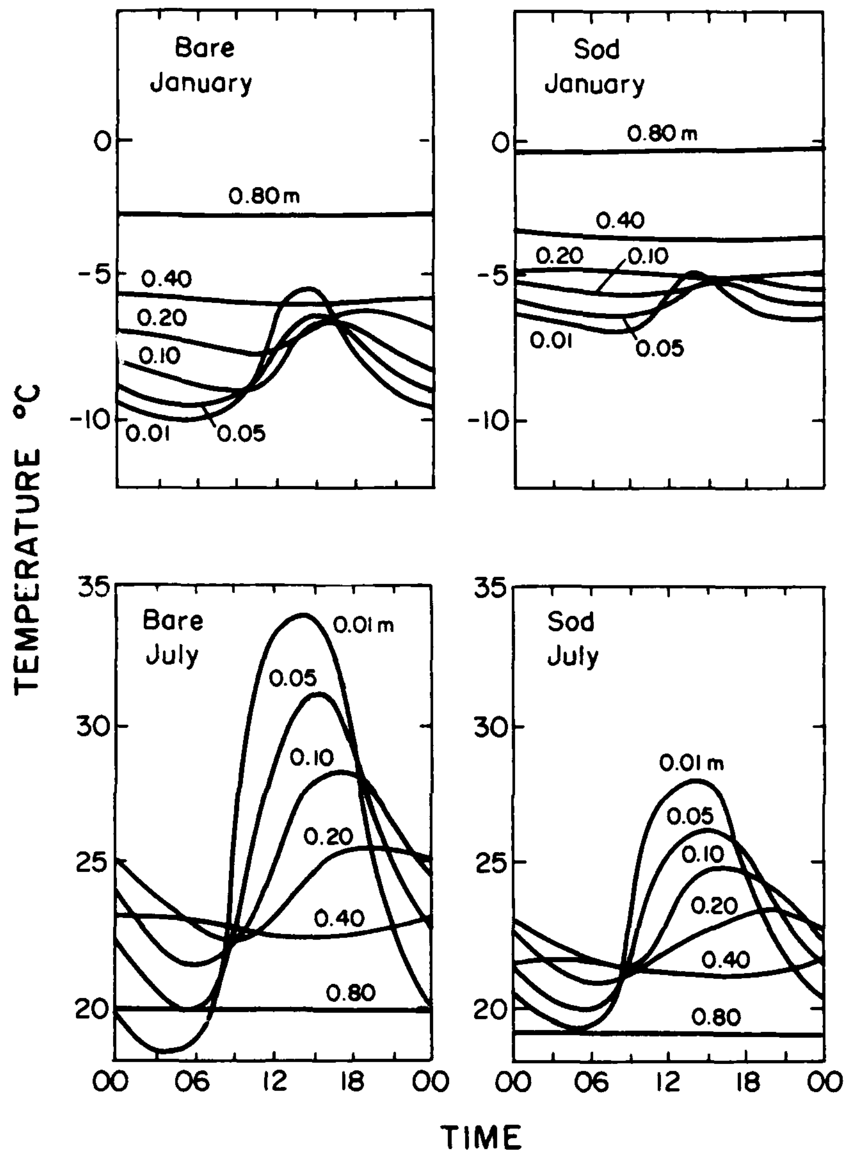

Figure 4. Average hourly soil temperature under bare and sod-covered soil at St. Paul, Minnesota, in January (top) and July (bottom). Soil depth is shown in m (modified from Rosenberg 1983).

artifacts.

18. Temperatures in both water and soil can be calculated with much greater confidence than applies in the ever-varying atmosphere. Some general statements that can be of use approximating thermal patterns in both media are given below.

Water

19. Water temperatures change very little during the day, only a few degrees even at the surface. The conditions at an archaeological site that has been flooded would approximate more closely to those of a lake or reservoir than those of the open sea. One of the most accurate and long-period records of water temperatures in a lake has been taken in Austria from 1927 to 1950. The surface mean monthly temperatures varied about 13°C (23°F) but at a depth of 10 m (33 ft) this had dropped to 8°C (14°F), from where it decreased steadily at 4°C (7°F) at 40 m (130 ft). The lake averages 125 m (400 ft) in depth and is 8 km (5 mi) long and 1-2 km (0.6-1.2 mi) wide.

20. Due to heat (cold) stored in the water, February is usually the coldest month while August or September are the warmest, the latter month being warmest at lower levels. The upper layers of the water are particularly susceptible to mixing caused by air flow acting through friction and turbulence.

21. The practical outcome of the above facts is that at any site flooded to a depth of more than about 5 m (16 ft) will experience only a small range of temperature during the year so that a few accurate measurements at selected times will yield a good idea of the thermal stresses to which the site is subject. One special and extreme case would arise when the upper layers of the water freeze during the cold season. If such freeze conditions affect part of the site the damage could prove severe. Also, the lake water turnover, occurring in the spring, could harm smaller artifacts.

Soil

22. As noted already, the critical variables in any such temperature calculations is the thermal diffusivity, k, of the soil. Some typical values of k are given below.

Values of k ($x10^3 cm^2 s^{-1}$)

Still air	150-250
Rock	6-23
Wet Clay	6-16
Wet Sand	4-10
Dry Sand	2- 5
Dry Clay	0.5- 2

23. The range of temperature at a certain depth decreases exponentially with k, while the time lag (delay in heat reaching a certain depth) is proportional to $1/\sqrt{k}$. Below

about 30 cm (1 ft) the daily temperature fluctuation is negligible while at 6 m (20 ft) the annual cycle is, for all practical purposes, insignificant.

24. Assuming there is a sinusoidal temperature wave at the surface (a reasonable supposition) then

$$R_Z = R_O \exp [-Z (\pi/k P)^{\frac{1}{2}}]$$

where R_Z is the annual range of temperature at depth Z, and P is the oscillation period (= 1 year).

25. The table below gives an idea of the change of range with thermal diffusivity.

<u>Depth at Which Annual Temperature Range is 1% of That at the Surface</u>

$k(cm^2 s^{-1})$	0.001	0.008	0.012	0.025
depth (m)	4.6	13	16	23

Note: (a) k increases with moisture content up to a maximum then it decreases;
(b) k increases with compaction;
(c) k decreases with organic content;
(d) k is not necessarily constant with depth.

26. An aspect of fundamental interest in soil thermal conditions is the freeze depth. Unfortunately, very little has been published on this topic. However, two maps have been obtained, one from the National Climatic Data Center (Asheville) showing the extreme depth of frost penetration (Figure 5) and one from the U.S.D.A. Year Book (1941) depicting the average depth of frost penetration (Figure 6). Data used to draw these maps are sparse and of irregular record lengths so that little reliability should be placed on isopleths shown in mountainous areas.

27. In the very top layers of the soil, the freeze-thaw cycle can be of great importance, in road pavement studies for instance, but at depths envisioned for buried archaeological sites (say below about 1 m) this should have relatively small impact provided there is no large variation in water content also. Information on the freeze-thaw cycle at other than instrument shelter heights or the surface to be non-existent. However, soil temperature data exist and analyses could be undertaken.

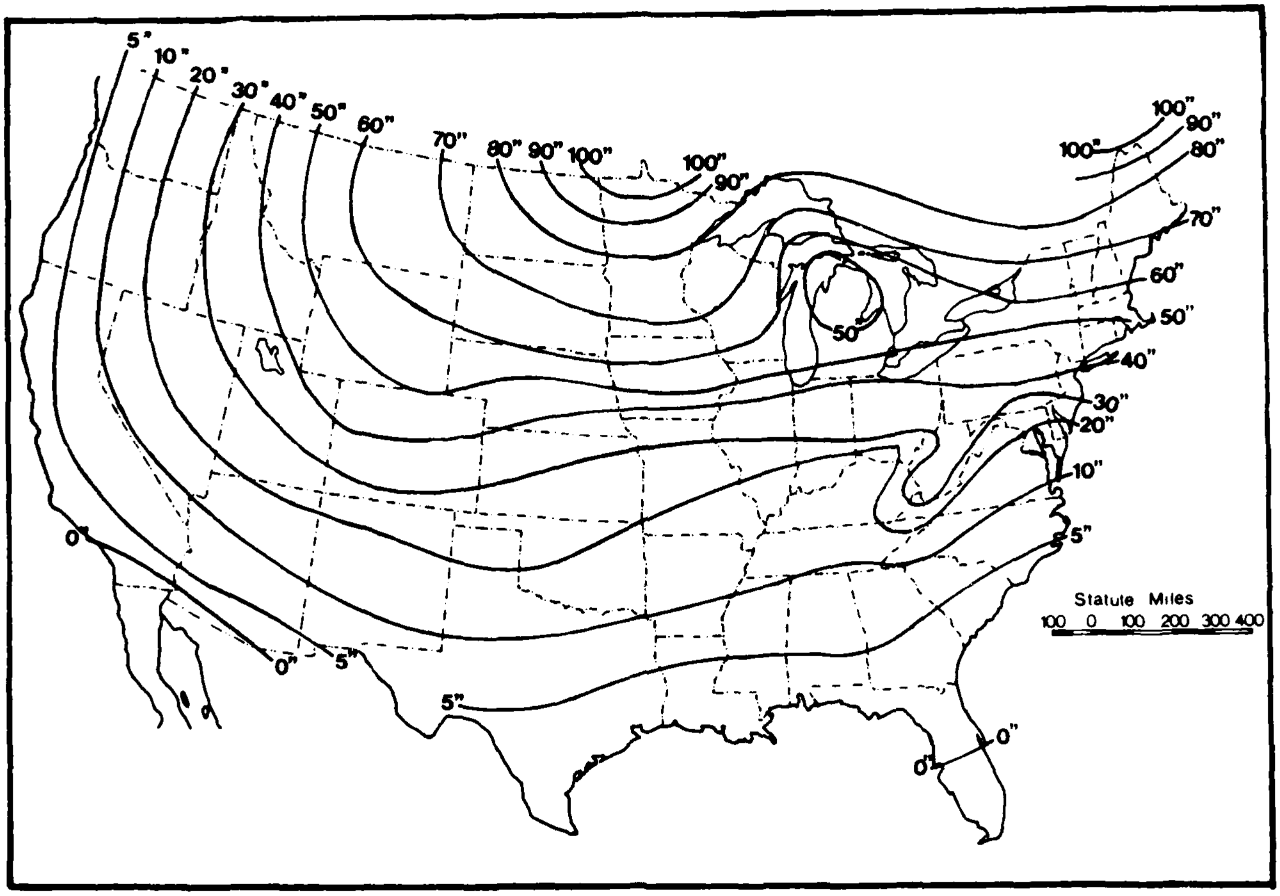

Figure 5. Extreme frost penetration (in inches) based upon state averages. Modified from U.S. Department of Commerce, Weather Bureau.

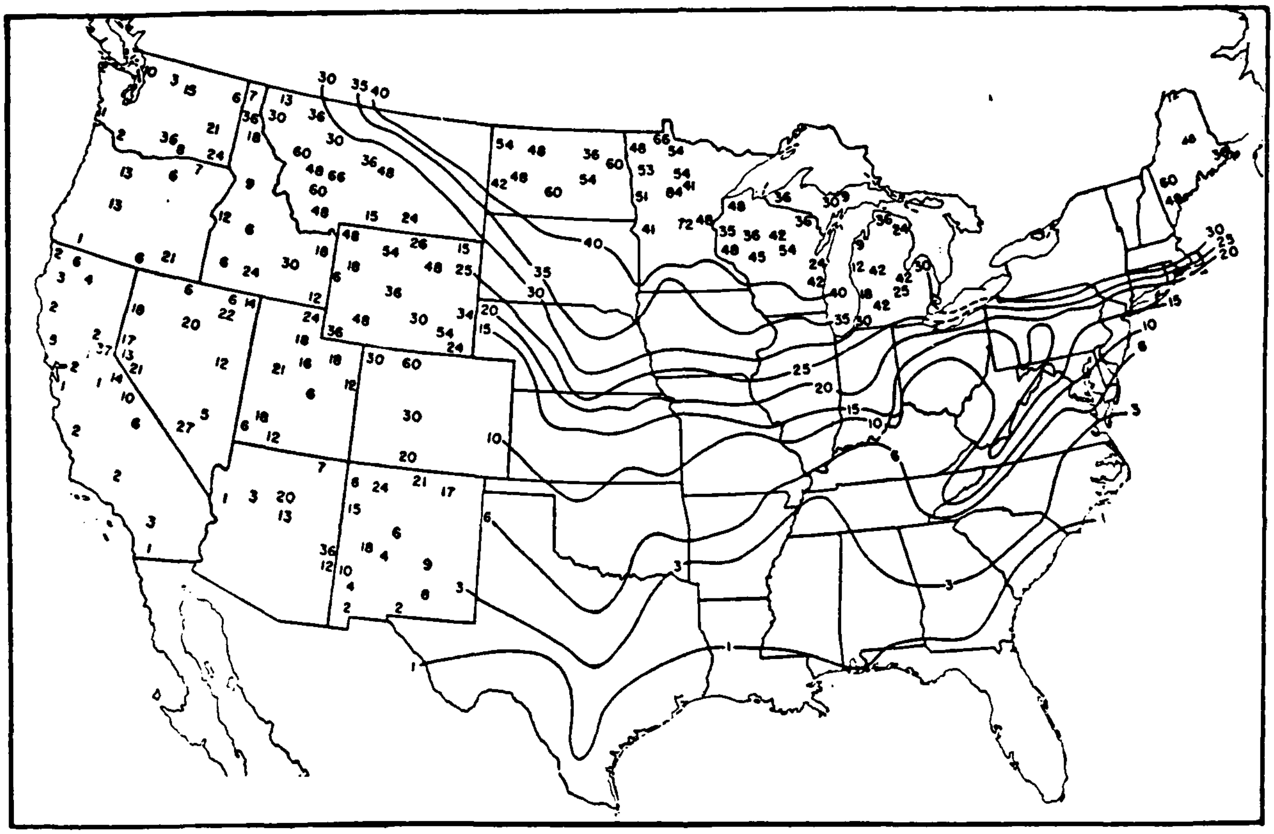

Figure 6. Average depth of frost penetration (in inches) for period 1899-1938. Information collected from unofficial sources.

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GEOMORPHIC PROCESSES AND ARCHAEOLOGICAL SITE PRESERVATION

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1. Natural geomorphic processes have either destroyed or buried more archaeological sites than have been found or which have been altered by man-induced impacts. The questions to be addressed in this chapter are: 1) Can known, identified archaeological sites be preserved from naturally occurring or man-induced geomorphic processes through burial? 2) What current geomorphic processes now acting on the site will be enhanced as the result of burial? 3) What current processes will be reduced, in magnitude and frequency, as the consequence of burial?; 4) Do existing engineered projects alter the natural processes such that the site is threatened? The answers to these questions are strongly dependent upon the site location in the landscape.

2. Surficial geomorphic processes can be classified as fluvial, aeolian, coastal, periglacial, mass wasting, tectonic, and volcanic.

3. Fluvial processes are those surficial processes resulting from the hydraulic action of channeled water flow (i.e., river systems). The system may be either large or small with the results of the process being either aggradational, degradational or stable. Degradational processes are most threatening to archaeological sites. With regards to archaeological sites the primary concern is with the threat of degradational processes. Two specific examples are the migration of meander loops and avulsions of river channels.

4. Meander migration is that natural surficial process where a channel moves laterally across a floodplain. An archaeological site located on a natural levee on the outside bend of a migrating channel will be destroyed. This can be thought of as a continuous low magnitude process. Each flow event, less than overbank or less than a flood event, will remove more of the outside bank thus destroying the archaeological site.

5. Avulsions may be thought of as catastrophic, or sudden, events in which changes occur in both channel shape and channel location within the floodplain. Whereas channel migration threatens sites near a channel, avulsions threaten any site located in the active floodplain.

6. A secondary level of destructive threat to archaeological sites from fluvial processes occurs out of the floodplains on riverine terraces and in the uplands. The specific processes in these areas are sheet erosion, rill erosion and channeled erosion such as the formation of gullies. The magnitude of these secondary processes is appreciably less than

the magnitude of the processes in the floodplains but they are also continuous.

7. Aeolian processes are those in which the driving force results from the movement of the atmosphere roughly parallel to the earth's surface - the wind. Archaeological sites which occur in semi-arid to arid environments may be threatened by aeolian processes. In sub-humid to humid environments the density of vegetation precludes wind speeds high enough to exceed the shear strength of the surface materials. The threats in the dry environments are degradational or aggradational as with fluvial processes. Aeolian forces through the process of deflation may exhume a site and expose it to surface or atmospheric driven processes of degradation. Aeolian forces may also bury a site. The natural process of burial may enhance degradation by raising the water table, increasing the incidence of organisms or several other conditions.

8. Coastal processes which pose a threat to archaeological sites are strikingly similar to fluvial processes. The agent, for the most part, is water, but it is now water driven by wind or longshore currents. The primary threat to archaeological sites in the coastal environment is one of erosion from waves, hurricane surges, washovers and littoral currents. As with the fluvial processes, littoral and wave erosion are continuous processes of relatively low magnitude, whereas hurricane washovers and hurricane surges are catastrophic events of high magnitude but low frequency.

9. Periglacial processes occur in two environments. Periglacial, defined as near the margin of glaciers, occurs in either Alpine or Arctic landscapes. Periglacial processes which threaten archaeological sites are those processes occurring within the active zone of freeze/thaw. Repeated freeze/thaw as a process is degradational or will enhance destruction of almost all archaeological site components. Both the physical artifacts and the spatial conformation of the site are subject to degradation and alteration. Downslope processes such as solifluction also can occur in periglacial environments and are degradational to archaeological sites.

10. Mass wasting is a general term used for a variety of processes by which masses of surficial materials are moved by the process of gravity. The movement may either be slowly or quickly from one place to another on the surface of the earth. The threats to archaeological sites from mass wasting processes are either burial, if the site is at the end of the movement of the surficial materials, or destruction, if the site is on the slope where the mass wasting processes take place.

11. Tectonic processes are almost always catastrophic in magnitude. Tectonic threats to archaeological sites that may be alleviated do exist. One example is to sites occurring on clays having high water content and subject to liquefaction upon shaking. Other tectonic activities such as earthquakes are a high threat to archaeological sites, and

protection to these sites by burial is probably not achievable and will not be discussed.

12. The last of the geomorphic processes is volcanism. By far the most significant volcanic process to an archaeological site is one of burial. Burial may be either by pyroclastic debris (ash) fall, lahars or by a flow of lava. In any case the site will be buried deeper. These processes are generally of low frequency but with highly variable magnitudes.

Forms and Landscapes

13. Landforms are the recognizable individual elements or features of a landscape. Scale is an important function of landform /landscape identification, description and interpretation. From an airliner at 30,000 feet only regional size landforms are recognizable while from the ground few of these are identifiable. At the other extreme is an archaeological site where the site is the landscape and only micro-landforms are identifiable.

14. The scale of the landform carries over into the scale of the processes which are creating or destroying the landforms/landscape. The processes are the same at both scales, but the capacity and competency change as the size of the landform changes.

15. Landscape location is concerned with all the questions of surficial geomorphology. What landforms make up a landscape? What processes both created the landforms and the landscape? How long did these processes act, and at what rate? Have the processes creating or destroying the landforms changed over time? What did the landscape look like and what processes were acting upon it at the time of archaeological site formation?

16. These, and similar questions, require at least qualitative, if not quantitative, answers before addressing the problem of whether burial will preserve the archaeological site.

Locational Elements

17. The position of the archaeological site within the landscape, that is, on what landform and what type of geomorphic system it is located, is critical to answering the question of preservation by burial. The achievement of preservation is highly location dependent. The location dependency can be determined by using the concepts of systems analysis. Simply stated, in systems analysis, one looks at the processes of inputs and outputs in terms of both energy and material flow into and out of the archaeological site. These inputs and outputs are controlled by position on the landform within the landscape. A site

may be then described in terms of surficial geomorphic processes as stable, destructive or constructive. A stable site position is one in which the inputs of energy and material equal the outputs of energy and material. A destructive position is one in which the outputs of energy and materials exceed those of input. Conversely, constructive sites are those in which energy and materials flow into the site in excess of what flows out. For a site to exist, its history must have been dominated by conditions of stable or constructive conditions. If relatively recent environmental changes have occurred, either due to natural alterations or due to engineered works, the site habitat may switch to conditions of degradation, and preservation techniques should be considered.

18. Some examples of stability, destructive and constructive sites can be given under the fluvial regimes of surficial geomorphic processes. Such examples would be:

a. Stable Situation ; a fluvial terrace that is not undergoing active sheetwash or fluvial fill would be a stable landform;

b. Destructive Situation; a site on a natural levee which is being actively eroded by meander migration or on an alluvial fan that is undergoing active incisement;

c. Constructive Situation; a site being buried by processes of an alluvial fan expanding out onto a flood plain or burial by colluvial deposits along a valley sidewall (Figure 1).

19. Once the site's location within the landscape and the individual landform have been determined, the degree or magnitude and frequency of geomorphic processes can be estimated. Once again, using the fluvial regime as an example, sites located on high riverine terraces or uplands are located away from the high magnitude destructive processes of the active floodplain. These sites are subject to such processes as sheetwash, rill erosion and gullying. These processes are continuous but at such low magnitude that properly engineered techniques can easily alleviate their destructive tendencies. On the other hand, an archaeological site located in a floodplain is susceptible to high magnitude destructive processes. The high magnitude processes may be things such as active lateral meander migration, which is continuous and directly destroys the site located on the bank. Another example of a high magnitude but discontinuous process is the process of avulsion, or major change of channel, destroying the site away from the current channel in the floodplain. Increased flooding and flood scour due to changes in land use and land cover would also be deleterious to shallow sites. The identical questions of magnitude and continuity or discontinuity apply to the other geomorphic regimes (Figure 2).

20. In an aeolian process dominated landscape, the engineered burial of a site may enhance the capture of wind-borne material and further bury the site. The impact of the

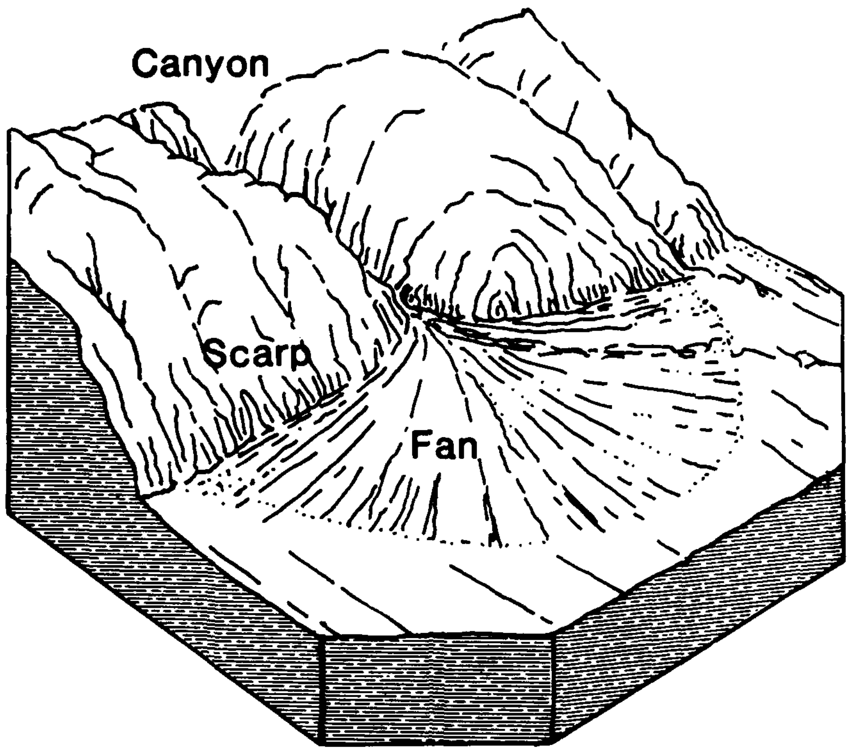

Figure 1. Alluvial fan: Archaeological sites are degraded by both fan construction (burial) and fan destruction (incisement of channels). (After Strahler, 1969.)

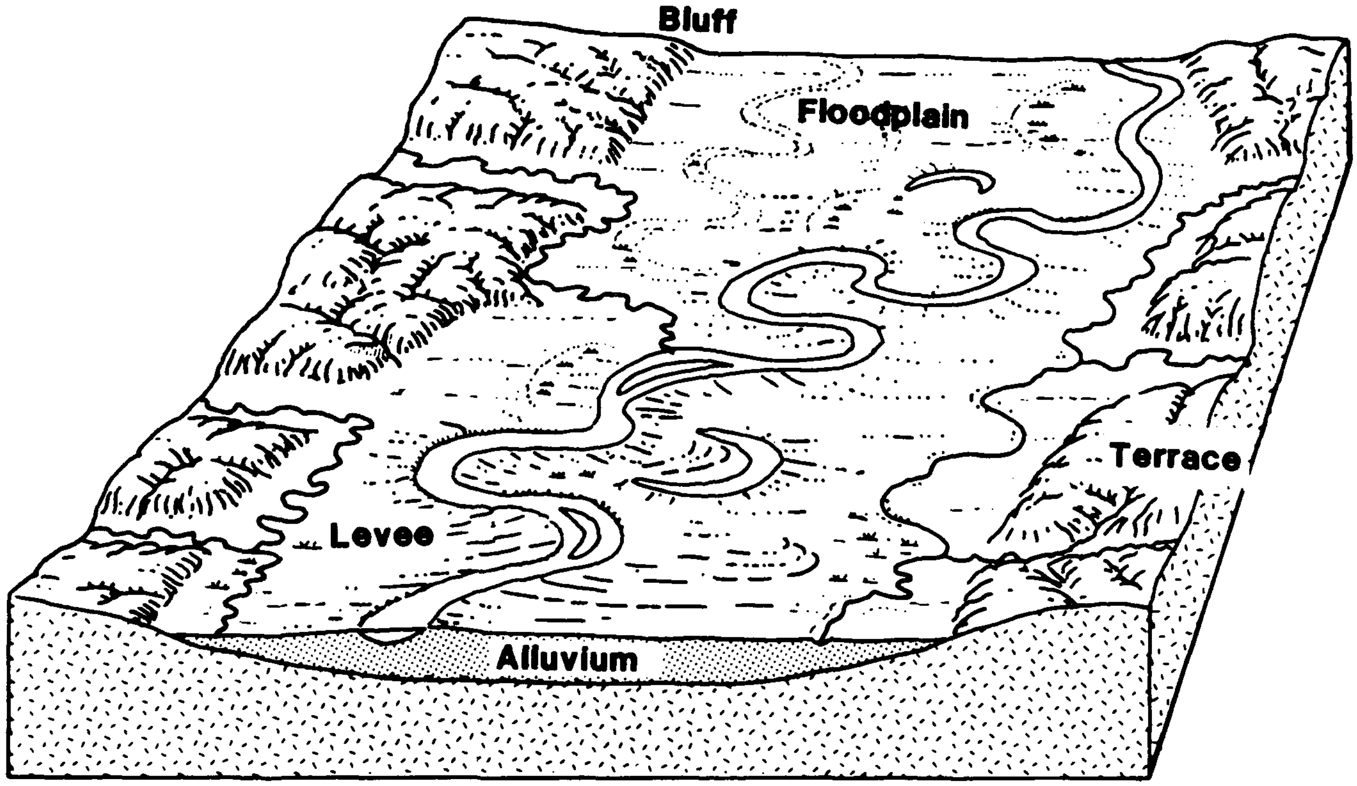

Figure 2. Fluvial Regime: Both channel avulsion and channel migration can degrade or destroy an archaeological site. (After Strahler, 1969.)

initial man-induced burial with the addition of naturally added materials may produce adverse effects of compaction, rise of water table, or increase in the attractiveness of the site to organisms.

21. On the other hand, the burial of an archaeological site may increase its topographic influence and switch the aeolian process from one of construction to one of destruction. The process of deflation may then become active and erosion of the site may occur, such as a blowout.

22. In a coastal regime the same questions are asked as in the fluvial regime. Although the processes are slightly different the impacts, or the threats, to the archaeological sites are very similar. The position of the archaeological site controls the threats of destruction. Whether the site is located on a foredune, a backdune, or a back tidal flat contributes to the answers of magnitude and frequency of the events (Figure 3). The problems raised by a site threatened by wave erosion are very similar to the problems raised by the lateral migration of a meander belt in the fluvial system. Hurricanes, on the other hand, fall under the same class as fluvial avulsions: catastrophic events occurring at widely spaced intervals with high magnitude threats to the archaeological site. The burial of the site located in an ancestral cut through the dune may, in essence, increase the destructive forces of undercutting, as the burial of a site on a natural levee may also increase the undercutting and consequent slumping. The threats to the archaeological site are controlled primarily by location within the regime of geomorphic process. Burial in a coastal site may also increase compaction if on a tidal mud flat of highly liquid compactable clays. Compaction in this case would have a very negative impact on the site components and their spatial relationships.

23. A site located in a regime of mass wasting processes has two basic elements of threat. If the site is located on an unstable slope, the addition of materials provided for the burial of that site may increase the load, exceed the coefficient of friction and increase the instability of the slope, with resultant destruction of the site by downslope movement. The downslope movement would undoubtedly cause some degree of "churning" and destruction of the spatial continuity of the site. It would also change the site's position in the landscape.

24. The second positional problem in the mass wasting regime occurs if the site is located at the toe of an unstable slope. In this case, the movement of materials downslope by mass wasting processes is slow and continuous; it may just further bury the site. On the other hand, if it is a rapid discontinuous movement it may dislocate and simultaneously "churn" the site, destroying both the artifacts and their spatial continuity (Figure 4).

25. The natural threats to archaeological sites in a periglacial environment may actually be reduced by burial. The primary threat to a site in the periglacial environment is

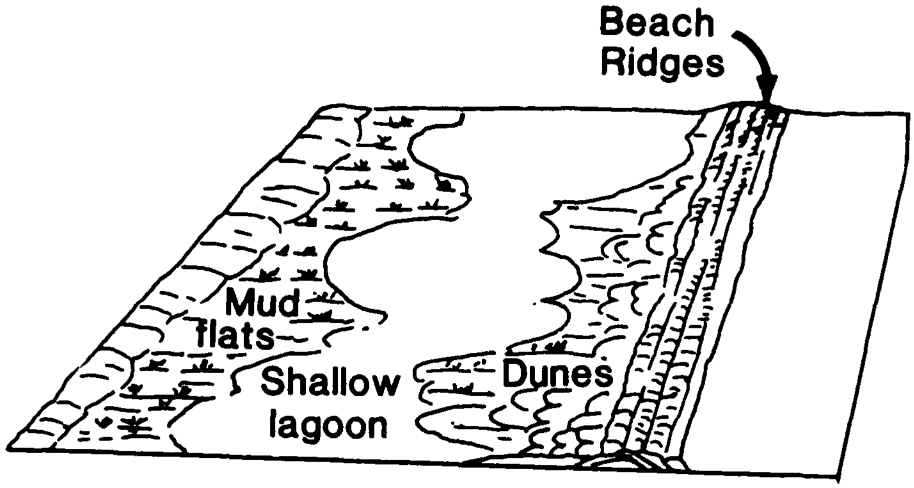

Figure 3. Landforms in a coastal geomorphic regime: Erosion of archaeological sites can occur on all landflows via wave, longshore current, or hurricane driven processes. (After Strahler, 1969.)

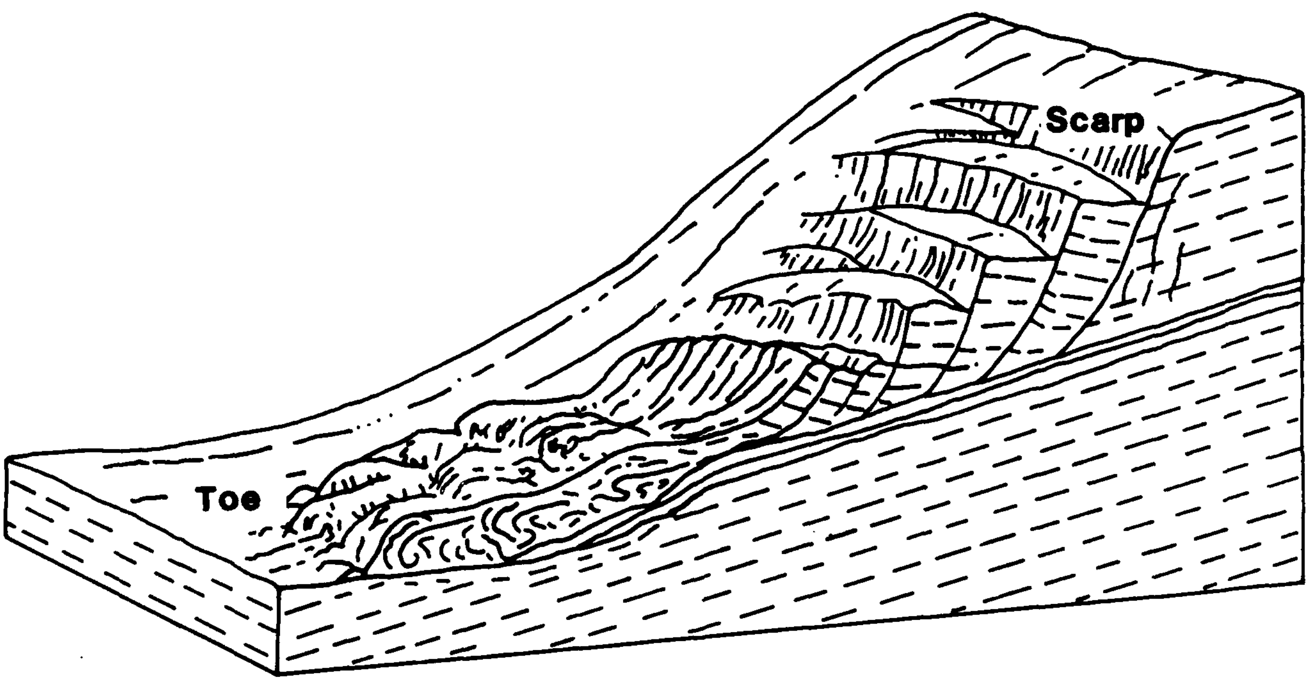

Figure 4. Mass Wasting - A Rotational Slump: Archaeological sits can be displaced, destroyed, or buried by these types of processes. (After Strahler, 1969.)

that of freeze-thaw cycles. Burial may very well raise the level of the permanently frozen ground so that the site is located within the true permafrost. This would eliminate the disruptions of the freeze-thaw cycle. The result will be enhancement of preservation of the site. In these environments, the depth of burial will be critical. The site must be buried deep enough to raise the level of the permafrost into the site itself, but not so deep that compaction destroys artifacts or the spatial relations.

26. Solifluction is a common phenomenon on low angle slopes in a periglacial environment. It is the result of repetitive cycles of freezing and thawing. Solifluction is usually a slow downslope movement of soil material. The soil material is usually saturated and the conditions for movement are enhanced by either shrink/swell or freeze/thaw. Burial may enhance the degradation of sites on slopes if the burial increases the site's mass above the threshold of the coefficient of friction and amplifying movement, distance, or both. Once again, the locational elements of the site are critical to the determination of preservation or destruction by the practice of burial.

27. The processes associated with tectonic activity and volcanism can both be considered as discontinuous, high magnitude events. In general, however, the magnitude of either tectonic or volcanic activity will greatly exceed the protective capability of simple engineered burial.

Conclusions

28. Assuming that a site has been identified and declared eligible for preservation techniques the next step is the analysis to determine the locational elements of the site. The resolution of which geomorphic processes are active follows the spatial identification of the site location.

29. Once the step of determining the site's geomorphic regime is completed, the analysis of site threats must be undertaken. The concept of site threats can be broken down into two classes: those threats that are due to active geomorphic processes acting under natural conditions, and threats which will be, or have been, created by engineering projects. The engineering projects may be already completed, or may be in the planning stage. An example of increased threat to archaeological sites by previously constructed engineering projects is the Upper Missouri River. The change in the regime of the Missouri River by the engineered dams, reservoirs and irrigation projects changed the flow of the river from a more or less entrenched channel to an actively migrating reservoir shoreline, destroying sites throughout the floodplain*. It is not critical to determine if the

*Hester, James, personal communication.

processes that threaten the site are man induced or natural. It is, however, critical to be able to list the forces or processes that threaten the site and determine, at least qualitatively, their magnitude and frequency of occurrence. These determinations of magnitude and frequency may then be used as the base line for all other disciplines involved in the engineering of the preservation burial technique.

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SOIL PROPERTY CHANGES UPON BURIAL

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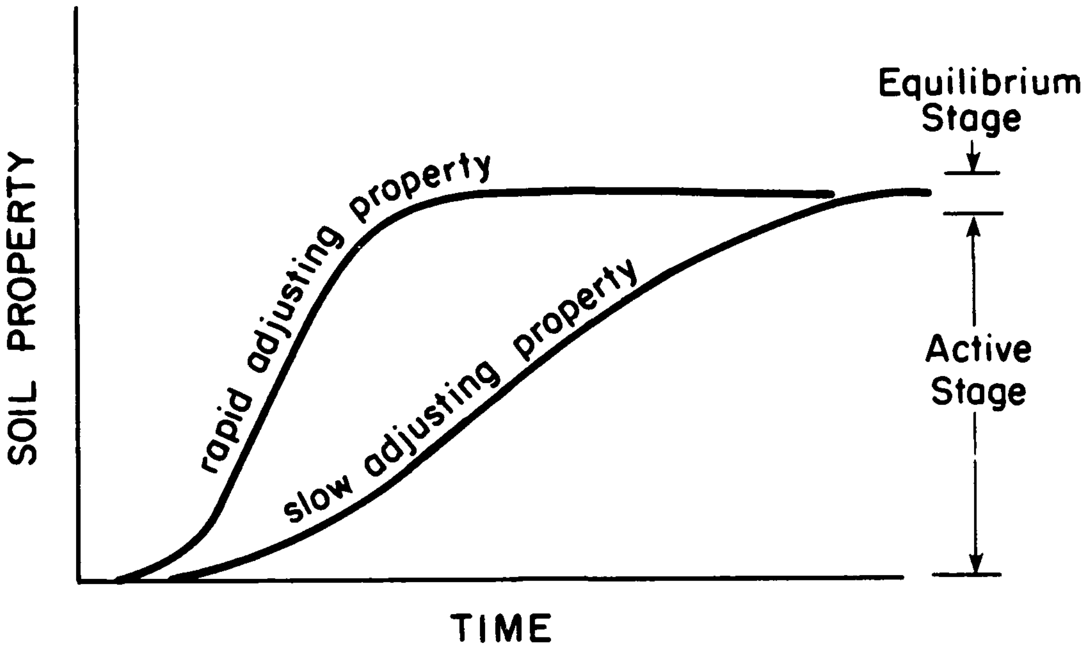
1. The term "soil" has a different meaning to laymen and professionals of varied disciplines. To the engineer, soil may be the unconsolidated earthy material which acts as subgrade for construction projects while the geologist may consider soil as the material above bedrock. Because the heritage of pedology is both in the geological and agricultural sciences, the definition that pedologists embrace reflects a hybrid historical background. Soil, for our discipline, "is the collection of natural bodies on the earth's surface, in places modified or even made by man of earth materials, containing living matter and supporting or capable of supporting plants out-of-doors" (Soil Survey Staff 1975). By specifically recognizing the influence of man on the soil resource, pedologists acknowledge that at least a portion of man's activity has lasting effects on the soil and that some soil properties may serve as a record of man's history, recording both his presence and impact on his environment.

2. Soils form on the landscape as a result of their environment, an environment of which they are a component. Jenny (1941) first wrote of this relationship in terms of five soil-forming factors - climate, biota, relief, parent material, and time. The soil occupying the landscape today is a function of the actions and interactions of these factors.

3. But soils are dynamic, responding to an environment that is dynamic at multiple levels. For example, as long-term climate changes occur, some soil properties may change while others are preserved, essentially reflecting a previous climate. On a shorter time scale, seasonal or even daily environmental fluxes drive soil property changes; an example is temperature and moisture. Yet, it should be noted that all soil properties are not equally dynamic, i.e., responsive to changes, nor equally able to record conditions of the past.

4. The rate of change of a soil property to its environment can be illustrated in Figure 1. Since all properties do not respond to their environment at the same time, curves for both rapid - and slow-adjusting properties are shown. Shapes presented in Figure 1 are for illustrative purposes only, as the exact shape of the curve may change with property and environment. The rate of change of a soil property is the slope of the line at any point, i.e., Δ property/Δ time. When the rate of change approaches zero, the soil property may be said to be in equilibrium with its environment. At any point in time, a change in the soil environment will effect a change in the rate process as well as the absolute value of the



Examples of rapid and slow adjusting properties in a leaching environment:

Rapid	Slow
organic matter	clay content
P content	Fe oxide content
bulk density	

Figure 1. Schematic relating change in soil properties with time.

property in question. Burial of the soil will always change the soil environment and affect rate processes. A knowledge of the new soil environment will be necessary to estimate or predict the response of the soil in any given property.

5. A traditional but selected list of soil properties is shown in Table 1 under headings of physical, chemical, morphological, mineralogical, and biological divisions. For the purpose of this paper attention will be focused on physical, chemical, and mineralogical properties.

6. Soil scientists recognize the critical role that water plays in shaping the character of the soil. The energy model proposed by Runge (1973) recognizes water as the effective agent for partitioning energy and generally decreasing soil entropy (Smeck, Runge and Mackintosh 1983). Even early (Marbut 1927, Baldwin, Kellogg and Thorpe 1938) and current (Soil Survey Staff 1975) schemes of soil classification separate classes in part on the amount and movement of water in the soil. To illustrate the importance of water on soil properties, consider two soil moisture regimes: aridic and udic. Aridic and udic regimes approximately equate to arid and humid climates, respectively, and they represent incomplete and a high degree of leaching of soluble components of the soil. Contrasts for the aridic and udic moisture regimes are shown in Figure 2. Due to the limited amount of water percolating through the soil in an aridic regime, products of chemical weathering such as soluble ions, are leached only to a depth controlled by the amount of water available to leach the soil (Jenny and Leonard 1934, Arkley 1963). Pedogenic calcite (calcium carbonate or free lime) accumulations are commonly observed in such soils. Calcite accumulations are seldom noted in soils with udic moisture regimes as sufficient water moves through the soil to leach soluble ions from the soil and into the ground water. Other contrasts are given in Table 2 to generalize the effect of moisture regime on the soil. These generalizations are sufficient to illustrate that the effects and degree of change of a site after burial would be highly dependent on both depth of burial and movement of water through the overburden and soil.

7. Mineralogical composition of both the soil and overburden will also strongly influence kinds, direction and intensity of chemical reactions, weathering, and mineral formation. Table 3, taken from a similar listing by Allen and Fanning (1983), shows the relative stability of selected minerals subjected to the soil environment. Other stability tables exist and much of the variation among tables is due to mineral size differences and weathering environment (Brewer 1964). The mineralogical composition of the soil strongly governs the soil solution composition. Of particular interest to many facets of archaeological study is quantity and mineral form of phosphate. White (1978) discussed the dependence of phosphate form on soil properties. White and Hannus (1983) also show

Table 1

Selected Physical Chemical Morphological Mineralogical and

Biological Soil Properties

Division	Property
Morphological	Color, horizon thickness, fabric or particle arrangement.
Physical	Infiltration, hydraulic conductivity texture, structure, bulk density, particle density, temperature.
Chemical	Organic carbon, reaction, cation exchange capacity, extractable/exchangeable bases/cations, soluble salts reduction-oxidation status, nutrient contents (phosphorus, nitrogen, potassium, etc.).
Mineralogical	Amounts and kinds of minerals, mineral stability.
Biological	Amounts and kinds of micro and macro organisms, biological nutrient transformations

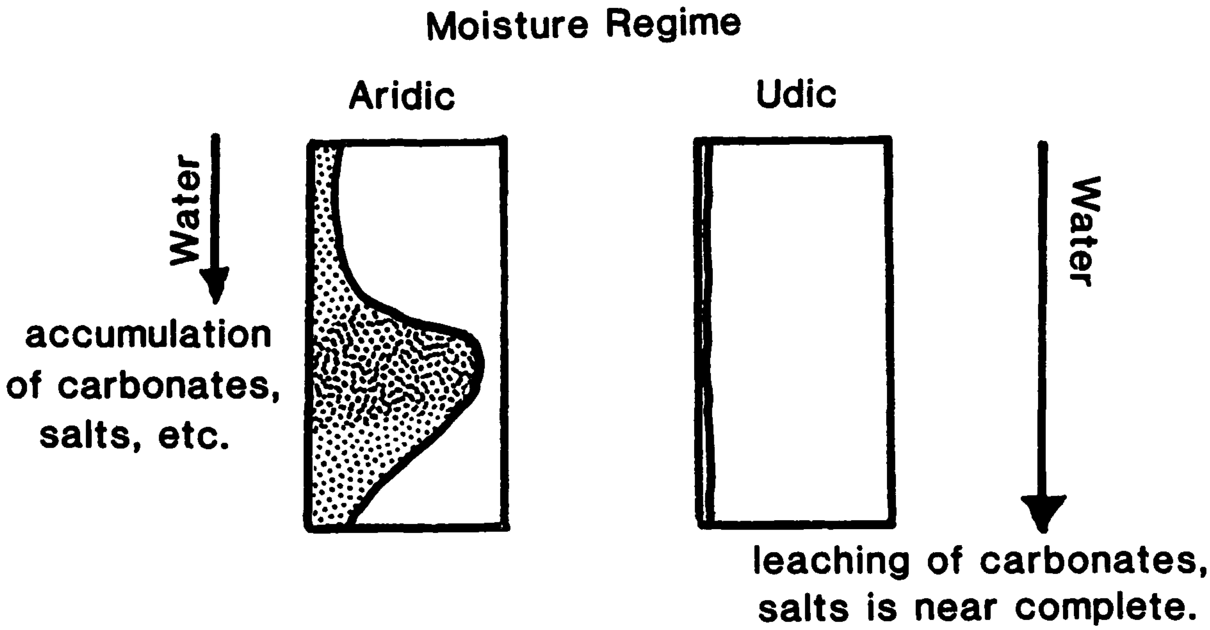


Figure 2. Illustrated differences of leaching intensity between aridic and udic soil moisture regimes.

Table 2

Relative Comparison of Soil Processes and Properties

Between Two Soil Moisture Regimes

	Soil Moisture Regime	
Process/Property	Aridic	Udic
mineral weathering	less	more
clay genesis	less	more
leaching	less	more
eluviation/illuviation	less	more
salt accumulation	more	less
organic C	lower	higher
bases	higher	lower
pH	higher	lower

Table 3

Selected Soil Minerals in Order of Decreasing Stability*

(from Allen and Fanning, 1983)

Primary	Secondary
Zircon	Anatase
Rutile	Gibbsite
Tourmaline	Kaolinite
Ilmenite	Pedogenic chlorite
Garnet	Smectite
Quartz	Vermiculite
Epidote	Illite
Sphene	Halloysite
Muscovite	Sepiolite
K-feldspar	Allophane
Sodic-feldspar	Calcite
Calcic-feldspar	Gypsum, pyrite
Hornblende	Halite (and other soluble salts)
Chlorite	
Augite	
Biotite	
Serpentine	
Volcanic glass	
Apatite	
Olivine	

* Sand and silt-size particles are assumed for primary minerals and clay-size particles for secondary species.

that weathering of bone is highly dependent upon soil calcium levels and presence of calcite plays a key role in the direction and rate of weathering.

8. In general, rate of weathering of minerals in the post-buried soil would be expected to decrease, but the actual rate would be dependent on numerous factors such as temperature, moisture regime, chemical composition of the soil water, mineralogy, redox potential, reaction and particle-size. Perhaps of more concern is the effect of burial on the formation of new mineral species in the soil or the abrupt change in the chemical composition of the soil solution resultant from burial. The greater the differences in properties between the soil and the burial medium (overburden), the greater the expected change in most soil properties as a result of burial. Consider an acidic, highly weathered soil which may be buried beneath a calcareous (containing free lime) overburden (Figure 3). Water moving through the overburden becomes base-charged and alkaline; upon entering the soil, exchange reactions occur which increase the base status and cation exchange capacity of the soil, raise the pH, and if the moisture regime is conducive, (leaching depth within the soil), new mineral species may form while other species may disappear. Degradation of bone would slow and if soluble Ca and bicarbonate levels were sufficiently high, a protective coating of calcite may form over bones, pebbles and other objects. Voids may become sites for precipitation of secondary calcite. Forms of phosphate would change from strengite and variscite-like minerals (Al, Fe-phosphates) to the calcium phosphate family of minerals. Burial of a non-calcareous surface horizon with carbonate-rich dredge by the Mayan Indians circa 900 A.D. in northern Belize has been found. The upper portion of the buried surface horizon has become calcareous while the lower portion still remains carbonate-free.*

9. Another possible combination would be acid overburden placed on a calcareous soil (Figure 4). Increased rate of carbonate dissolution; weathering of primary minerals; and decrease in exchangeable bases, soluble ions such as Ca^{+2}, and pH would be expected to result. Again, formation of minerals at and near the overburden/soil interface would probably occur, particularly Fe and Al oxyhydroxides. Rate of bone degradation would increase and soil phosphate forms would change from Ca phosphate to strengite and variscite.

10. In addition to changes which can occur due to chemical discontinuities created by burial, physical discontinuities can also disrupt rate functions. Water moves through the soil along pores. Sudden changes of porosity, such as fine-textured overburden on a coarse-textured soil or a coarse-textured overburden on a fine-textured soil would greatly influence pore continuity and water movement (see Figure 5). Changes in pore continuity

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*Jacob, John, personal communication.

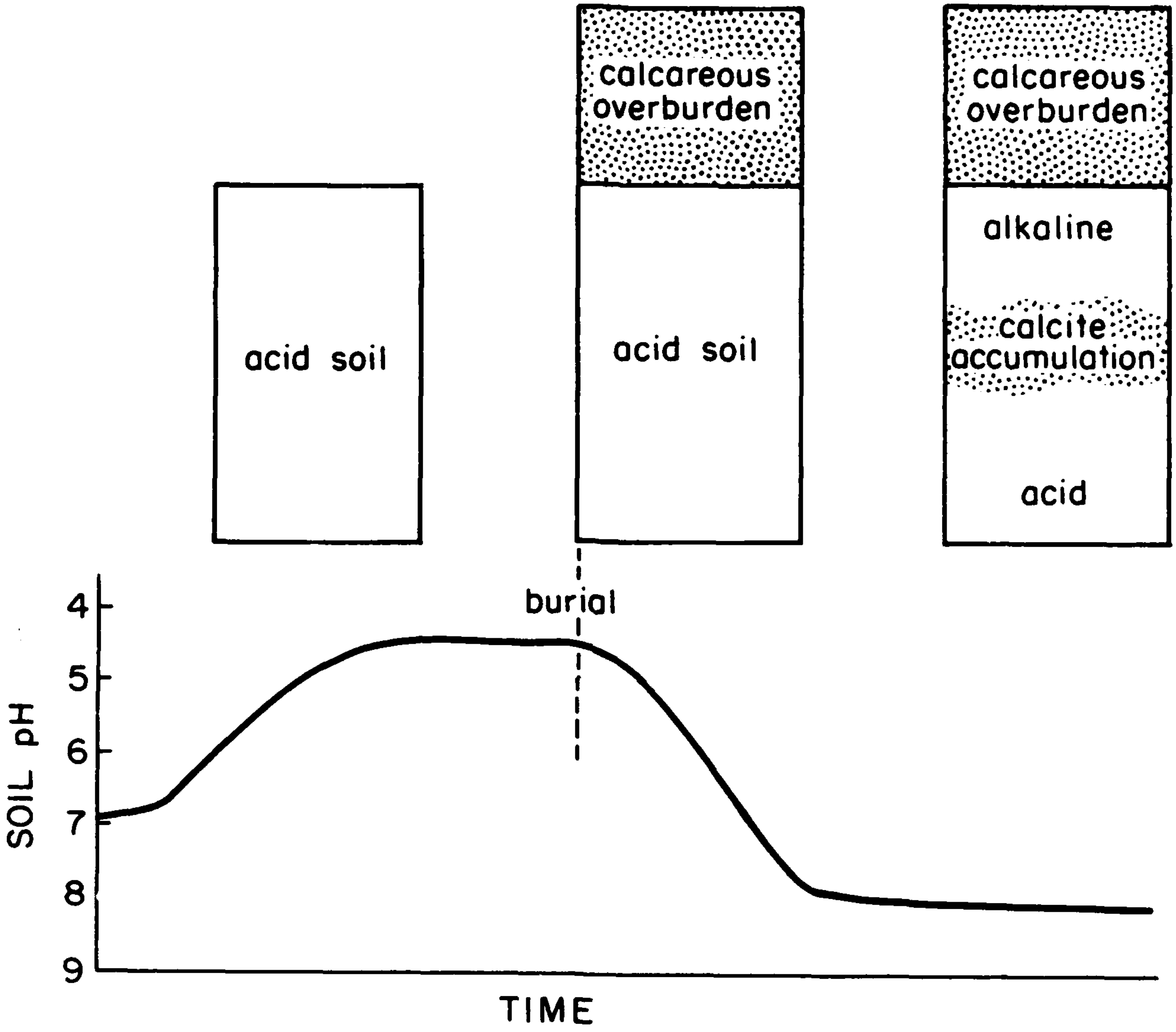

Figure 3. Idealized change in soil pH with time after acid soil is buried beneath calcareous overburden.

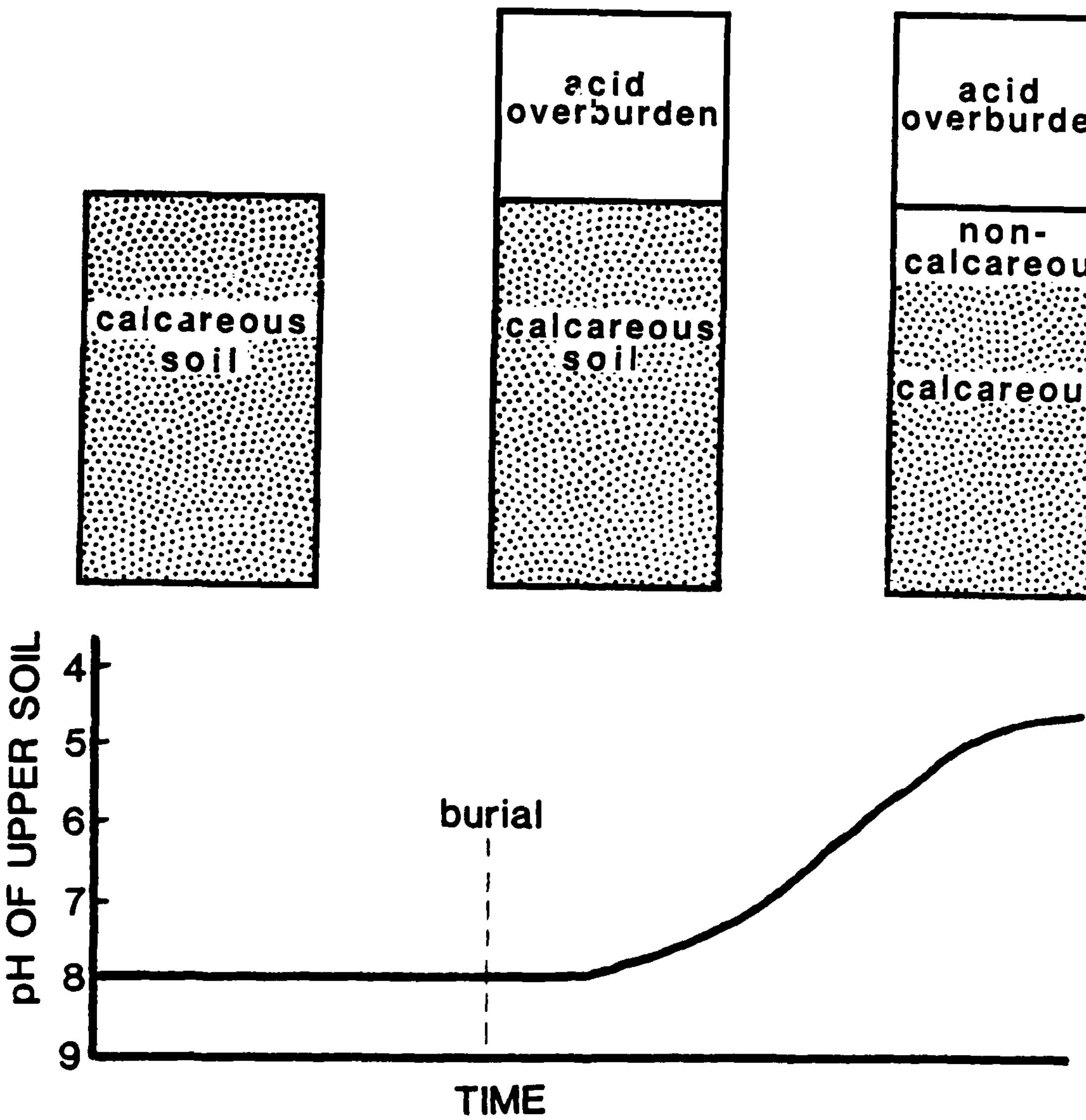

Figure 4. Idealized change in soil pH with time after calcareous soil is buried beneath acid overburden.

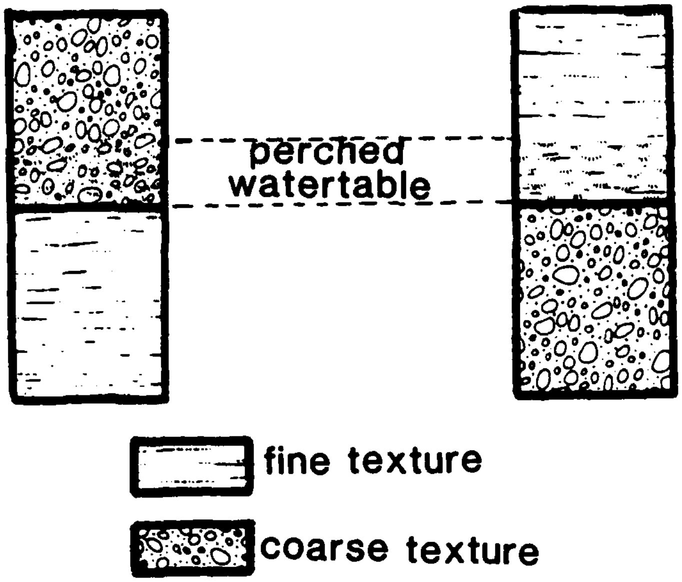

Figure 5. Schematic showing disruption of pore continuity and formation of a perched water table above layers of contrasting particle size distribution

disrupt water flow and may result in perching water at the interface between overburden and soil. Reducing conditions may develop within and below the zone of perched water, effectively altering the moisture regime and initiating cycles of oxidation-reduction that were not previously present. The interaction of Eh (redox potential) and pH influence ionic and mineral species of elements which may undergo oxidation/reduction changes in soil. Forms of Fe and Mn minerals and the oxidation state of their soluble phase commonly found in soil are dependent on pH and Eh (Collins 1968). Changes in pH and Eh also greatly affect the rate of metal corrosion in soil (Moore and Hallmark 1987) and would be of concern in preservation of historical sites which might contain metallic artifacts.

11. Since both physical and chemical discontinuities between soil and overburden accelerate changes in the soil, a good guideline would be to carefully match the burying material to the soil. This should minimize site alteration. Care should be exercised not to embrace the theory of placing packed clay over the soil and expecting the treatment to seal off water from entering the soil. Such an approach would offer opportunity for short-circuit water flow along major cracks that would likely form in the clay, i.e., acting as a funnel to concentrate water to the soil-overburden interface.

12. Burial could afford some degree of protection from physical disturbance (fauna/flora pedoturbation) such as man, rodent, insect, crayfish activity and tree throw. Thickness of overburden should probably be adjusted based on material and moisture regime. By careful consideration, minimum change could result but almost certainly some change will occur. At question perhaps are the kinds of changes that are acceptable or unacceptable and the length of time for which protection is desired.

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INVERTEBRATES THAT DISTURB BURIED ARCHAEOLOGICAL MATERIALS

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1. Invertebrate animals can disturb buried archaeological materials in three ways: by direct consumption, feeding on materials that have been degraded by fungi or bacteria, or mechanical disturbance. The kind of disturbance depends on the conditions under which the material is buried, the type of material itself, and the species of invertebrates that can gain access to the site.

Environmental Conditions Affecting Disturbance by Invertebrates

2. The most important condition regulating disturbance by invertebrates is the moisture content of the soil. Many accounts of the natural history of soil animals are descriptive, reporting various groups from "moist" or "damp" soil, rather than giving exact percentages of soil moisture. There seems to be general agreement, however, on distribution of various groups going from saturated to arid soil (Figure 1).

3. Saturated to moist soil is preferred by animals that respire directly through the body surface: protozoans, some oligochaete worms, and nematodes in particular. Protozoans live in films of water on and between grains of soil. Among the oligochaetes, white worms (Enchytraeidae) tolerate saturation better than most, although as a general rule the earthworms can remain submerged at least for a few days (Edwards and Lofty 1972).

4. Animals in the middle range of tolerance for soil moisture require moisture for respiration, but respire by modified gills, tracheae, or book lungs. Isopods cannot tolerate complete submergence (Sutton 1972). Land snails tolerate a relatively wide range of soil humidities, but die at greater than 80% soil moisture content (Evans 1972). Common earthworms (Lumbricidae) are most abundant in areas with 12-30% soil moisture (Edwards and Lofty 1972). Millipedes vary in their ability to tolerate submersion, with some able to tolerate up to 24 hours submergence during periods of flooding (Blower 1955). Pauropods can be common at 11-20% soil moisture depending on the clay content (Cloudsley-Thompson 1958). The insects and Acarina (mites) range from moist soil to arid conditions, but require air for respiration (Birch and Clark 1953).

5. Very arid soils often are poor in soil invertebrates. However, desert nematodes

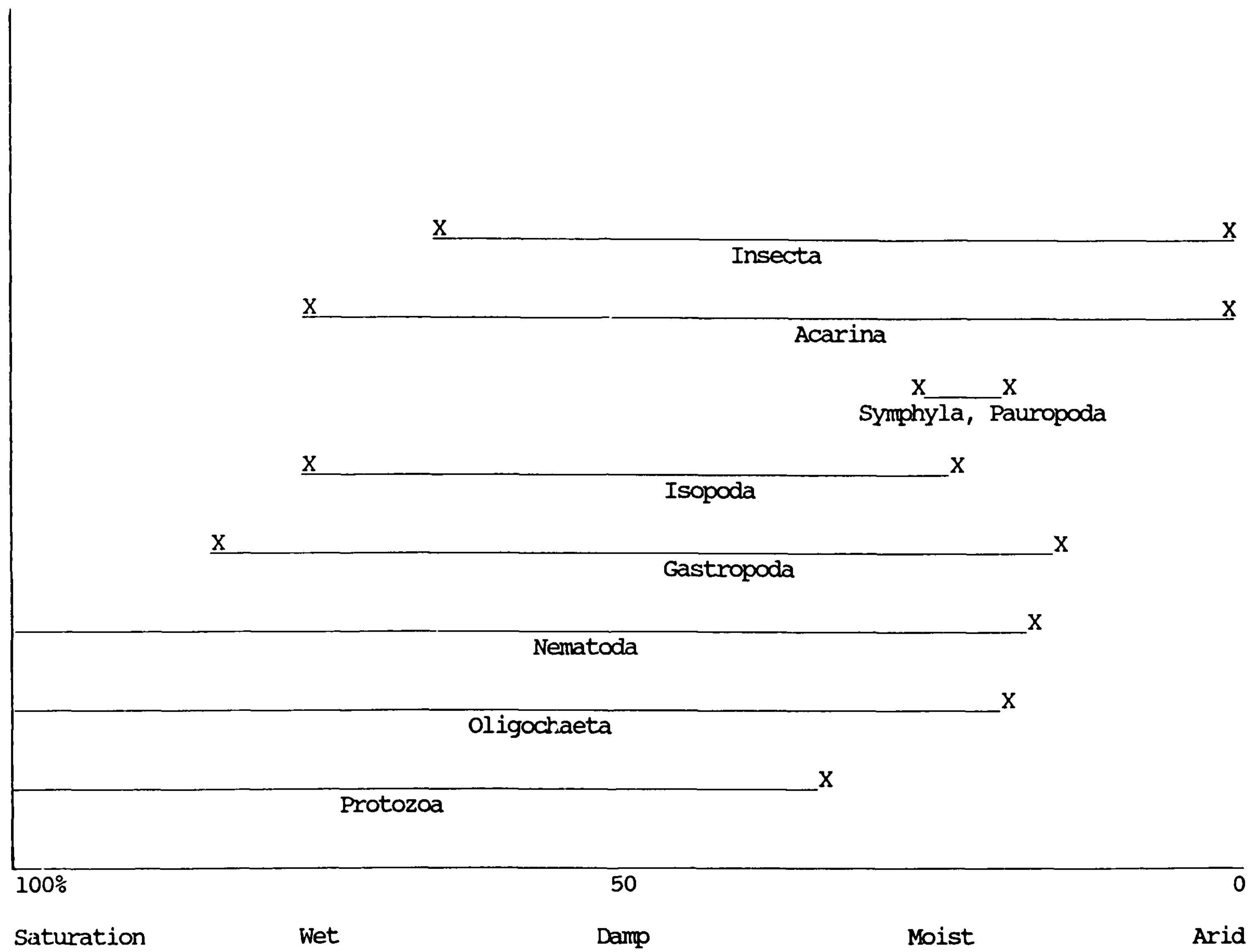

Figure 1. Distribution of animal groups according to soil moisture saturation.

can produce resistant eggs or go into a state of aestivation, allowing them to survive through arid conditions and resume activities after rainfall (Whitford, et al. 1982). Earthworms tend to dig deeper burrows under arid conditions. Certain species of desert land snails aestivate, resuming activities after heavy rains (Solem 1974). Desert ants can dig elaborate burrows that reach deep water levels.

6. The grain size of the soil governs the ability of animals to burrow, as well as the penetration of air and water, and the pore space between particles. The greatest diversity of species occurs in a mixed soil of sand and humus. Such soils support protozoans that live in water films as well as diverse fauna of larger animals, including various worms and arthropods. (See Kuhnelt 1955, for an extensive list, and Kevan 1955, for keys). Sandy soil tends to drain quickly or lack the cohesion necessary for permanent burrows, while clays offer resistance to burrowing and tend to pack tightly, halting flow of air and water. Nematodes cannot move freely in soils without adequate water films (Nichols 1984). Soil protozoans tolerate temporary dry conditions in the soil by producing cysts, but they eventually must have water films between soil grains.

7. Soil-dwelling animals prefer a soil with a pH close to neutral. Most earthworms are common at a pH around 7, although a few can tolerate conditions down to a pH of 4.3 or up to 9.2 (Edwards and Lofty 1972). Soil nematodes can tolerate anaerobic conditions for short periods of time (Nichols 1984).

8. The presence of calcium in the soil is important to animals that incorporate it into the exoskeleton or require it for physiological processes. Earthworms, land snails and larger millipedes (subclass Chilognatha) do not live in soils without calcium. However, these animals can extract calcium from bone, limestone building blocks, or cement. and snails among human remains may have been scavenging on bits of flesh, clothing or wood, or perhaps scraping the bones for calcium (Evans 1972).

9. Soils tend to have lower temperatures than the surrounding surface temperatures. Most soil animals are found at around 15-17^{o}C, but earthworms and others remain active down to nearly freezing. Isopods can tolerate higher temperatures if in highly humid conditions (Sutton 1972). Firebrats (Thermobia domestica) are tolerant of an extreme range of temperatures, but are most abundant in moist areas at the high temperatures of 37-39^{o}C (Ebeling 1975). Soil animals are killed by freezing. In extreme environmental conditions, soil animals such as land snails, nematodes and earthworms tend to go into dormancy or produce resting eggs that can overwinter. In deserts, many species dig deeply. Small arthropods may migrate vertically in the soil during warm days.

10. As a general rule, there are more animals in the soil closer to the surface than at great depths. Most species occur no deeper than 5-10 cm in the Arctic (Petersen and

Luxton 1982). In well-drained soil, however, animals may be found to 2 m deep. Earthworms can burrow to depths of over 2 m (Edwards and Lofty 1972), while ants can dig down to more than 6 m (Wilson 1971). Smaller soil animals will take advantage of burrows of larger ones, such as earthworms or gophers, in reaching greater depths in the soil.

11. Earthworms, nematodes, mites and other soil animals are attracted to organic material in the soil. A single rotting apple has been found to contain over 90,000 nematodes (Barnes 1980). The local distribution of many species tends to be patchy.

Decomposition of Organic Material in Soil

12. Most buried organic material, man-made or natural, decomposes through processing by the community of plants and microbes of the soil. Moisture is of primary importance, for it stimulates the initial attack by fungi or bacteria. The rate at which these primary decomposers attack the material depends on the local temperature as well as the conditions of the material - embalmed, dried or tanned material, for example, does not decompose as rapidly as untreated material. Medical examiners have found that the rate of decomposition of buried cadavers, human or animal, varies according to the cause of death, embalming procedures, speed of burial after death, whether or not a coffin was present, and what may be local soil conditions (Motter 1898).

13. In the presence of adequate moisture, fungal spores germinate, sending thread-like strands called hyphae over the material. Different species of fungi will attack plant or animal materials, depending on the chemical constitution of the material. The hyphae form a network called mycelium, giving the material an appearance like cotton. Bacteria grow by fission, forming films over material. The liquified byproducts of fungal or bacterial digestion may encourage soil algae to grow in the area.

14. Most of the common soil animals do not feed directly on buried organic materials. Birch and Clark (1953) and Peterson and Luxton (1982) have summarized the relationships among the many small animals that form the forest soil community (Figure 2). The growth of fungi and bacteria attracts worms, insects, crustaceans, and other arthropods that feed on decomposing plant litter. These animals possess strong jaws or tough feeding structures that can bite or chew off pieces of decomposing materials. Evidently, the animals digest mostly the bacteria or fungi on the material rather than the tough cellulose or protein fibers of the litter itself, but the ultimate effect of the chewing is to break down the litter further, exposing yet more surface area to microbial decomposition. The fragmentation also allows leaching of soluble minerals from the material and accelerates

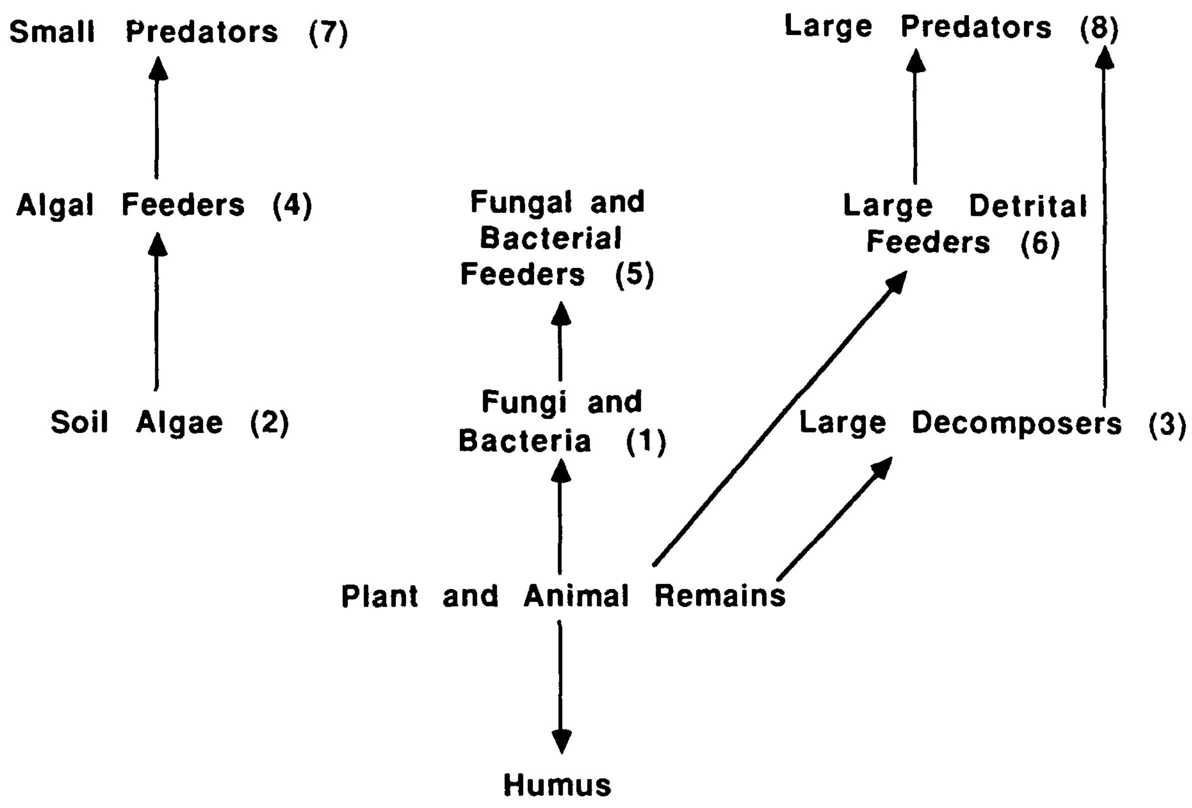

Figure 2. Ecological grouping of soil and decomposing animals based on feeding habits. Group 1: primary decomposers; 2, algae that grow on fluids around decomposing materials; 3, termites, flies and other animals that feed directly on remains; 4, algae-feeding protozoans; 5, common soil animals including mites, collembolans, nematodes, millipedes, isopods, etc; 6, earthworms, millipedes, etc. that feed on pieces of remains after attack by fungi or bacteria; 7, spiders, centipedes, predatory mites, etc; 8, moles, shrews, lizards, etc. (after Birch and Clark 1953; Petersen and Luxton 1982).

mineralization of plant litter. The physical disturbance of the chewing and movement of materials increases processing of the material by bacteria and mites. Soil processed by earthworms in particular is rich in bacteria, either due to mixing of surface material in the soil or nutrient enhancement of the soil during passage through the worm's digestive tract. Soils disturbed by earthworms were particularly poor in seeds and botanical remains (Ghilarov 1963; Went 1963).

15. Small animals of the soil feed on the soft hyphae or bacteria on decomposing material rather than chewing off pieces. Particularly common in all soils are the orbatid mites and springtails (order Collembola). Although Birch and Clark (1953) classified these animals strictly as fungal feeders, more recent laboratory studies indicate that 73% of those tested fed on at least two trophic levels in the soil community, eating algae, nematodes, and fungi. Apparently, many species are opportunistic, switching their feeding modes according to availability and nutritional value of food (Walter 1987). These abundant small animals in turn support various predatory animals (spiders, nematodes, protozoans, etc.) that may be found in the soil. (See Figure 3.)

16. Many of the characteristic decomposers of plant and animal debris live close to the soil surface. One expects a decrease in species diversity with depth of burial. However, an old study of the fauna associated with graves in Washington, D.C. (Motter 1898) found about 75 species of invertebrates, including insects, mites, millipedes, land snails, and various worms at depths of up to 6 feet (1.5 m). The list of species included many characteristic groups of the soil litter fauna, and noted the presence of "mold" on coffins and cadavers. The burials were in moist, sandy soil, at times in areas that had been submerged. The conditions probably were optimal for many soil organisms that might be confined to lesser depths in more hard-packed or arid soil.

17. In deserts, the arid conditions inhibit the growth of fungi. Santos and Whitford (1981) compared effects of exclusion of fungi versus microarthropods on decomposition of desert leaf litter. When fungi were excluded, decomposition was reduced by 29% from that of fully exposed litter. Use of a pesticide reduced decomposition by 53%. Most of the decomposition was due to a successional series of mites, which attacked the litter at different periods of time after burial. Nematodes, although present in the samples, had less effect on decomposition. The authors noted that fungal decomposition tended to increase after rainfall, when the area temporarily was wet.

Direct Feeding on Buried Materials

18. The amount of moisture in buried organic remains greatly affects the rate and

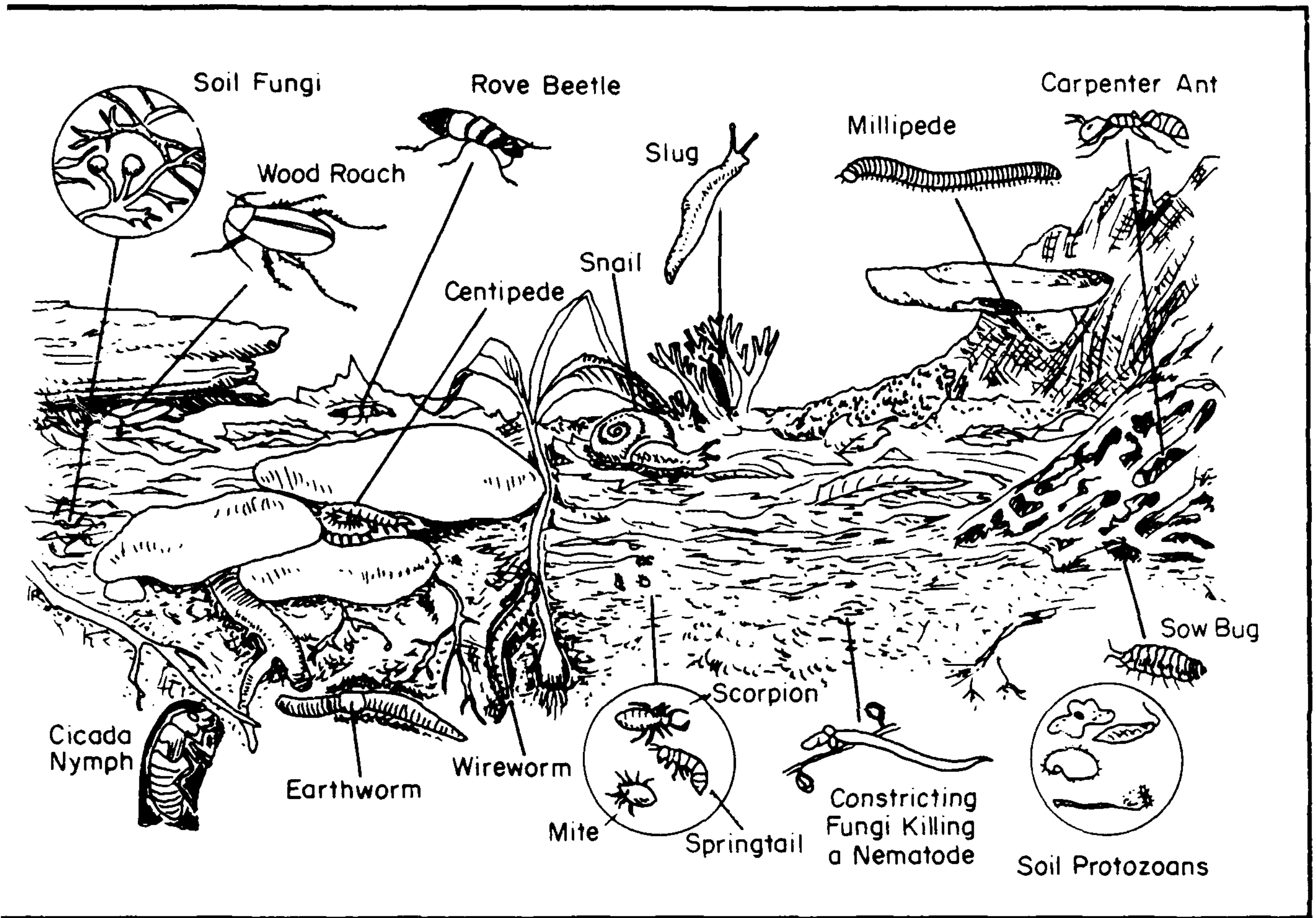

Figure 3. Animals of the soil (modified from Smith 1980).

amount of damage by invertebrate animals. Plant or animal materials that are liquified by bacterial decomposition or moistened by rain are much more likely to be consumed than hard, dry materials. Fresh or liquified animal tissues attract, among others, nematodes, land snails, isopods, flies, beetles and ants. Flies in particular are a problem, not only feeding on the tissue but laying eggs and leaving their larvae and pupae in the flesh. Locating their food source by scent, flies arrive quickly and reproduce at the site.

19. Osborne (1983) found that assemblages of scavenging insects at latrines and refuse dumps differed little in species composition between modern and archaeological (15th and 16th century) sites. Except for a few introduced species of insects, the same suite of scavengers was present. The archaeologist using insect remains as a guide to conditions at the site might be cautious if the site has been exposed - it could be difficult to distinguish between modern and ancient scavengers.

20. Wet plant material usually is attacked by fungi. However, a few animals possess enzymes that can digest structural polysaccharides such as cellulose, or have internal symbiotic organisms that can carry on such digestion. Land snails may possess cellulases (Cameron and Redfern 1976), while isopods, millipedes and insects such as earwigs have been observed feeding on larger plant remains. In damp places, silverfish (Order Thysanura) feed on starch-containing products, such as books, curtains, linens, silk and loose paper. Flies have been attracted to the fluids in old flower vases in mausoleums (Ebeling 1975). Isopods, earthworms and flies have been reported to consume dung. On rare occasions, invertebrate remains may become mineralized when fluids from decomposing materials come into contact with copper. Platt (1980) photographed an Anglo-Saxon brooch etched and coated by a mass of preserved nematodes that probably were attracted to a decomposing corpse.

21. Dried plant or animal material tends to be tough and difficult to digest. Only animals with strong jaws and appropriate digestive enzymes can feed on such materials. Some of these species, such as flour beetles (family Tenebrionidae), are able to synthesize water from the carbohydrates that they digest (Sokoloff 1972). Dry wood and hard plant parts are consumed by termites and carpenter ants (<u>Camponotus</u> spp.). The larvae of larger wood-boring beetles may attack wood near the surface. Beetles of the family Lyctidae burrow into dry wood and furniture. Clothes moths (family Tineidae) and small beetles (family Dermestidae) eat fabrics. Flour beetles, mites and weevils consume stored foodstuffs. Scavenging insects such as ants and cockroaches will damage fabrics including nylon if the fabrics are stained by attractive materials such as animal fats (Ebeling 1975).

22. Dry animal tissue, including meat, fur, leather and wood, usually is consumed by insects. Scavenging termites and ants will feed on available animal tissues, but the most

damaging consumers are beetles (family Dermestidae) and the maggots of various flies, particularly the families Calliphoridae and Sarcophagidae. Flies usually are not found alive in burials after about two years (Motter 1898). Dermestid beetles are particularly persistent, feeding on materials as tough as dried specimens in museums. Dermestids do not require moisture or fungi for feeding, making them a pest even in arid conditions. If these insects can gain access to a site, they quickly will reproduce and begin to feed. (See Boror, DeLong and Triplehorn 1981, for accounts of feeding in the various families of insects). Bone and hair usually are the last animal tissues to decompose.

Mechanical Disturbance of Buried Materials

23. Larger animals of the soil can move objects, undermine them, bury them, or open up passageways for air, water or smaller animals. Particularly well studied are earthworms (family Lumbricidae). The worms burrow through the soil, taking in soil mixed with decaying organic matter as they feed. Edible materials are extracted in the worm's digestive tract, inedible soil and wastes are passed as tubular castings.

24. The tunneling and feeding of worms moves considerable soil yearly: Darwin (1881) estimated that the movement of soil by worm castings in a British pasture per year was equal to a layer 5 mm deep. Edwards and Lofty (1972) estimated that worms could move 2-250 metric tons of soil per hectare per year, or a layer of soil equal to 1-5 cm. In Kentucky, Stein (1983) found that in 51 years, a population of about 3 million earthworms could ingest and disrupt the entire matrix of the mound.

25. Over time, burrowing and feeding by worms increases drainage by allowing water to pass through the burrows. This movement can undermine monuments, pavements and buildings: Darwin's book contains many illustrations of toppled stones, subsided walls, broken pavements, etc. covered by the characteristic soils formed by the action of worms. Smaller animals also can gain access to buried materials through the burrows.

26. Atkinson (1957) pointed out that as worms burrow, they tend to move small objects from the surface downward. Bottle tops, coins and other small objects tend to slip into the burrows. The castings and earth movements of the worms bury these objects or allow them to slip into buried chambers or cavities. The archaeologist who depends on coins, beads or other artifacts for dating a site is likely to be confused by a mixture of objects of different ages. The tunneling of the worms also tends to mix up occupation layers in a site. Species of earthworms that line their burrow chambers with stones can move small objects horizontally as well as vertically. Earthworms under good conditions could obliterate stratification, obscure boundaries and alter soil chemistry so much that

interpretation of buried remains becomes very difficult.

27. Ants and tropical termites build extensive underground nests. Many species build systems of tunnels, which serve to ventilate and insulate the colony. These tunnels allow water and air to enter the soil. Ants often build mounds, which disturb the soil.

28. In the arid parts of the United States, harvester ants (Pogonomyrex) build very deep nests, often more than 3 m x 7 cm in diameter in 3 months, and produce a dome-shaped mound with shafts and chambers extending to the water table in 2-3 years (see Figure 4). The ant hill of the British species of Lasius grows at 0.9X the age of the colony in years, producing after 10 years, a mound 22 cm high by 84 cm wide and extending down to 2 m. It is estimated that the African ant Camponotus acvapimensis mines 0.5% of the soil volume within 0-25 cm of the surface (Brian, 1983). These animals tolerate dry conditions by digging deeply enough to reach moist layers of the soil. Particularly interesting to the archaeologist or paleontologist is their habit of piling small pebbles, gravel, dead insects or small hard objects around the edge of the mound. Small man-made objects (beads, for example) or microfossils (teeth of rodents, lizard bones, etc.) also can be found in these heaps. (See Goetsch 1957 and Cole 1968 for illustrations of the mounds and burrows of ants).

29. Leaf-cutter ants (Atta spp.) are major crop pests in the tropics. These ants collect pieces of plant material, take them underground, and cultivate fungi that grow on the leaves. They then eat the fungi. The habit of eating plant specimens could be a nuisance to the scientist, but a greater problem is their extensive excavating for their nests. Atta texana , which occurs in the southeastern United States, builds enormous systems of tunnels and chambers. Related species of Atta have been reported to excavate soil equal to 22.72 m^3, weighing approximately 40,000 kg. Colonies of Atta can have 1-2 million ants occupying a nest with craters measuring 8 m^2, 40 chambers ranging from 8-14 cm deep and tunnels 2-3 cm wide connecting the chambers (Wilson 1971).

30. Particularly in the southeastern United States, burrowing crayfishes can excavate extensive tunnels and chambers. (See Figure 5.) These animals construct characteristic "chimneys" of mud at the entrance to the burrow. Commonly found in low-lying areas, damp woodlands, swamps or meadows, crayfishes can burrow down at least a meter to the water table. The burrowing of crayfishes can be a nuisance to farmers and gardeners, particularly where the animals are common. The aptly-named crayfish Fallicambarus devastator has been reported to produce over 25,000 earthen mounds per acre (Hobbs and Whiteman 1987). Crayfish burrows surely could disturb archaeological materials.

31. Desert isopods, relatives of the garden pillbugs, have been reported to build

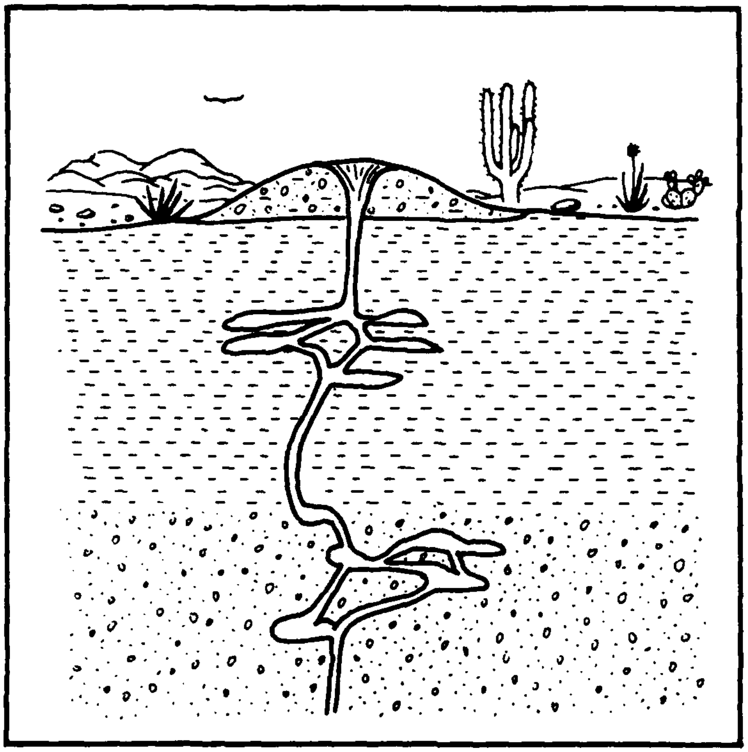

Figure 4. Nest of a desert harvester ant, Pogonomyrex (modified from Goetsch 1957).

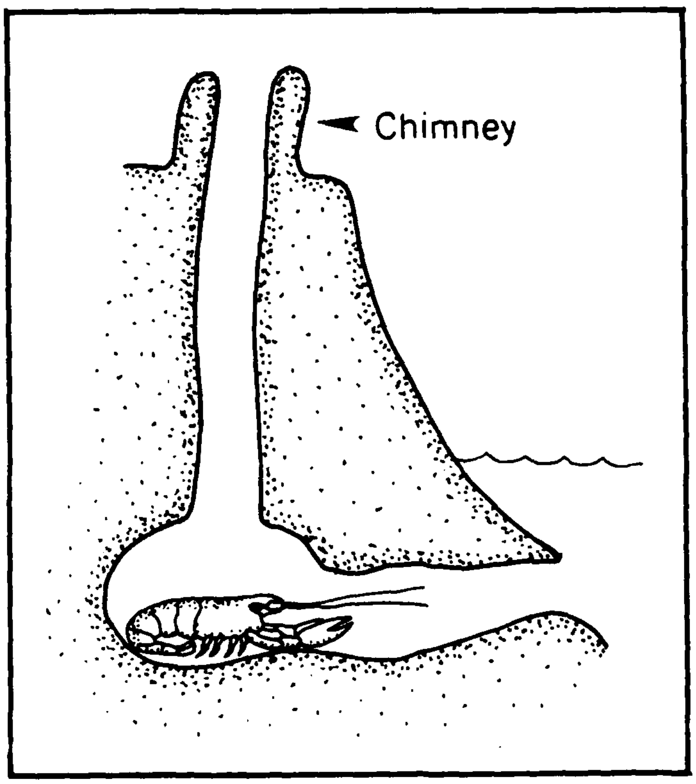

Figure 5. Burrow of a crayfish.

burrows 5-6 mm in diameter and "many centimeters in depth." These burrows can undermine slopes and cause local alteration in soil moisture and chemistry (Cloudsley-Thompson, 1977).

Recommendations

32. In preventing damage of buried sites by invertebrates, either a very wet or very dry soil is best. The majority of species prefer intermediate to somewhat dry conditions. Moisture is necessary for the growth of fungi, primary decomposers in the soil and a major food source for animals that fragment plant or animal remains. Restricting moisture among perishable remains or applying a fungicide could be good means of preventing damage. Deeper burial also aids by preventing many species from reaching the materials. A cover of hard-packed clay with few pore spaces will inhibit nematodes, protozoans, earthworms and most arthropods.

33. Damage by insects, which can be severe, can be inhibited by closing off access between the site and the surface or taking steps to reduce the flow of air to the site. Pest control companies and agencies regularly seek to control ants and termites through use of pesticides and barriers. Common means of restricting their access to buried wooden foundations or other structures is the construction of a "seal-off": excavated soil and the exposed parts of the structure are treated with strong pesticides, then a concrete barrier is prepared between the structure and the adjacent soil (Ebeling 1975). Such a barrier also could be useful in halting burrowing crayfishes, or preventing them from reaching the water table. A "seal-off" could be a particularly effective way of keeping invertebrates out of buried sites.

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BURROWING VERTEBRATES AND THEIR ROLE IN ARCHAEOLOGICAL SITE DECAY

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Introduction

1. This paper was developed in response to the need to understand ways in which burrowing activities of terrestrial vertebrates are known to (or might be expected to) affect the deterioration of archaeological sites. Of primary concern are the means by which burrowers vertically and/or horizontally displace archaeological materials or otherwise alter stratigraphy of such a site.

2. The plan of this paper includes (1) a definition of burrowing and discussion of reasons for and means of burrowing, (2) a discussion of soil characteristics, (3) a general inventory of North American vertebrate species that can be classified as burrowers with detailed treatment of selected species, (4) an examination of burrowing species as decay agents, (5) an examination of non-burrowing species as decay agents, (6) a conclusions section with projections of impact by burrowing vertebrates on newly-buried sites in various environmental settings, and (7) suggestions for further research.

About Burrowing

3. "Burrowing" is defined herein in broad terms. Burrowing includes activities of animals which spend virtually their entire life history underground in rather extensive tunnel systems (a highly-fossorial lifestyle) as well as of those which spend most of their time on the surface, retreating to shallow burrows only occasionally (a semi-fossorial lifestyle).

4. Reasons for burrowing are extremely diverse. Virtually every aspect of life is conducted underground for highly-fossorial species such as pocket gophers and moles. For most burrowing species, however, only a few activities occur within burrows or involve digging not associated with burrows. Many vertebrates dig shallowly in search of foods such as roots, stems and seeds of plants, larval and adult insects, and various invertebrate and vertebrate species. A variety of species burrow as a means of seeking shelter from predators or from undesirable or intolerable physical conditions (e.g., excessively high or

low temperatures) existing on the surface. Burrows, whether simple and shallow or deep and extensive, may serve as sites for laying eggs, or for brooding, hatching and rearing young, or for nesting for purposes of rest or sleep.

5. Timing and duration of use of a burrow varies widely by species and by purpose of burrow. Shallow foraging runs of moles and of certain other species usually are used only once whereas their deeper tunnels may be used for life and, perhaps, for generations. Hibernators and estivators use burrows on a seasonal basis to escape cold and heat, respectively. Burrows may be entered and exited on a daily basis, such that they are occupied at night by diurnal species and during the day by nocturnal species.

6. Digging is accomplished in a variety of ways (Hildebrand 1982). Most commonly, as seen in carnivores (dogs, cats, etc.) and many rodents, forelimbs and/or hindlimbs are modified (e.g., broadened hands and feet, strong claws, limbs geared to deliver great power) for "scratch-digging" via alternate flexion and extension of the limbs. Moles have modified forelimbs that operate on the basis of rotation of the upper arm (humerus) rather than via flexion/extension. Various rodents, especially pocket gophers, have highly modified dentitions in which the incisors, which are robust, forwardly-directed, and evergrowing, are used as chisels. In the preceding cases, soil usually is transported to the surface or into other sections of the tunnel system.

7. Burrowers using the following approaches generally do not move soil substantial distances; rather soil is displaced and often compacted into space immediately adjacent to the burrow. Legless diggers (plus a few species having reduced limbs), such as some snakes, salamanders and others, are termed "soil crawlers." Their bodies tend to be long and slender and their heads rather firmly-built. Modified nose regions and broadened skulls usually serve as the digging instruments. "Cover-up digging" includes the simplest means of burrowing: An animal covers itself only shallowly by tossing soil onto exposed body parts or by shuffling down into the substrate or by vibrating its body until submerged or by diving into soil or otherwise. Some species employ a combination of these methods in their burrowing, whereas others may not dig their own burrows, but instead will use systems constructed by some other species.

Soil Characteristics

8. The soils occupied by many burrowers, especially those that excavate extensive systems, usually can be described as "friable," that is, capable of easily being crumbled, pulverized or reduced to powder. The most friable soils are sands, silts and loams. Such soils are suitable to some burrowers even if small pebbles or gravels are intermixed.

Friability implies a moderate moisture content; a primary value of soil moisture is that it facilitates packing of excavated material and can thereby enhance the structural integrity required to prevent collapse of tunnels. Very dry soils generally do not offer needed structural integrity. Excessive moisture is undesirable for the obvious reasons that mud is messy and is difficult to dig through. Additionally, the necessary exchange of gases with the atmosphere is inhibited by high soil moisture. Appropriate soil moisture also helps achieve the controlled humidity regime characteristic of most burrow systems.
Although most burrowing vertebrates require friable substrates, some (especially amphibians; also the semi-aquatic star-nosed mole Condylura cristata) burrow through mud.

9. Depth of burrowing is determined by a number of factors. Deep burrowers, such as those of pocket gophers and gopher tortoises, will not dig deeper than the extent of friable soil. Likewise, they normally will not burrow into the water table. Indeed, geographic distribution of such species correlates well with depth of ground water level and with depth of a hardpan or other strata of unfriable substrate (Wilkins 1987). Biological factors, of course, also are important determinants; generally a burrower digging to locate food will dig only as far as necessary to encounter food items.

Inventory of Burrowing Vertebrates

10. An exhaustive list of burrowing vertebrates would be quite lengthy because most terrestrial vertebrate species do, in some manner, breach the ground surface in some aspect of their natural histories. Each of the four classes of terrestrial vertebrates includes burrowing species. This section includes a general taxonomic listing of semi- to highly-fossorial vertebrate species and indicates general distribution in North America and the extensiveness of their burrowing activities.

Amphibians (Class Amphibia)

11. This class includes the frogs, toads, salamanders, and caecilians. All amphibians require external bodies of water during at least some phase of their life histories. Some species are completely aquatic (some salamanders) whereas others (many frogs and toads) come to water only in connection with their reproductive needs; amphibians lay eggs in rivers, streams, lakes, ponds, ephemeral puddles, etc.

12. Many salamanders, genus Ambystoma for example, are not active for much of the year, spending most of their time inactive beneath the ground surface in burrows located under stones, logs and other objects or in burrows produced by other species such as ground squirrels, pocket gophers and badgers. They emerge briefly during rains, usually

in autumn, winter or spring, for breeding. This genus ranges over most of North America (Stebbins 1966).

13. An array of toads and frogs occupies burrows. The spade foot toads (genus Scaphiopus, family Pelobatidae) live under objects and in burrows ranging in depth from a few inches to several feet. Their burrows are usually self-made by using hindfeet with specialized spade-like tubercles. These toads may also occupy rodent burrows (Stebbins 1951). North American distribution extends from Canada to southern Mexico from coast to coast (Stebbins 1966).

14. Probably the most commonly-known toads are those of the genus Bufo (family Bufonidae). They range over most of North America as far north as the Arctic Circle (Stebbins 1951, 1966). These may reside in rodent burrows, but often construct their own non-extensive burrows. Bufo cognatus, the Great Plains toad, excavates shallow basins into which their bodies fit flush with the ground surface.

15. The common bullfrog, Rana catesbeiana (family Ranidae), lives in burrows beneath objects or in tunnels beneath stream banks (Stebbins 1951). Its general distribution covers much of North America east of the Rocky Mountains (Stebbins 1966).

Reptiles (Class Reptilia)

16. Living members of the class Reptilia include the turtles, tortoises, lizards, snakes and crocodilians. At least some members of each of these groups can be considered to be burrowers, although only a few are highly-fossorial.

17. Skinks and other lizards demonstrate a range of burrowing abilities (Milstead 1967). For example, the Great Plains skink (Eumeces obsoletus) can dig burrows up to one foot deep in loose, fine-grained soils, whereas burrows of E. fasciatus, the five-lined skink, rarely exceed depth of 3 inches. The ground skink, Scincella laterale, is not known to burrow. Lizards in general will reside under objects such as sunken flat rocks or in crevices and rock piles.

18. Like lizards, few snakes are extensive burrowers (Shaw and Campbell 1974), although many do spend a considerable amount of time below the surface. The head of hog-nosed snakes (e.g., Heterodon nasicus) has a sharply-keeled, upturned rostrum which drills via semi-rotary twists of the head, through the soil as the snake searches for food. Despite this feeding adaptation, hog-nosed snakes do not dwell underground. The gopher snake (Pituophis melanoleucus), despite its name, is not a burrower although it spends much of its time inside the tunnel systems of pocket gophers, ground squirrels and other prey species. Entry into a plugged tunnel system often is accomplished through use of the head to penetrate the plug and of coils of the anterior portion of the body to remove loosened soil. Gopher and hog-nosed snakes occur widely over much of North America

(Stebbins 1966)

19. Many of the other species of burrowing snakes occupy sandy and slightly rocky soils and often are called "soil swimmers" (Shaw and Campbell 1974). The shovel-nosed snakes (genus Chionactis) spend much of their time slightly beneath the ground surface. Other shallowly burrowing snakes include the banded sand snake (Chilomensicus cinctus) of the southwestern United States, the rubber boa (Charina bottae) of the Pacific northwest, and the hook-nosed snakes (genus Ficimia) of the southwestern United States and adjacent Mexico. None of these form lasting tunnels; rather the soil collapses behind the snake.

20. Box turtles (genus Terrepene) do not burrow extensively, although they dig shallow hibernacula usually 2 to 8 inches (rarely 1 to 2 feet) in depth (Pope 1949). However, some species of tortoises of the genus Gopherus excavate burrow systems that often are quite extensive. The gopher tortoise, Gopherus polyphemus, of the southeastern United States digs burrow systems of average length of 14.5 feet (Pope 1949) and maximum known length of about 40 feet.* They reach depths to about 12 feet, a level above water table but not so shallow that the system is not in "slightly damp earth" (Pope 1949). Only about 15% of the volume of earth dug to produce such a system is ejected onto the surface. The rest, about 85%, apparently is compressed radially into the soil adjacent to the tunnel system (Pope 1949). Such radial displacement of soil serves to strengthen the tunnel walls and to reduce the amount of downwardly percolating water that enters the burrow.

21. Burrows of the Texas tortoise (Gopherus berlandieri) may be as long as about 4 feet and about 1 foot deep (Auffenberg and Bradley 1969). In areas of sandy soil, this tortoise probably digs most of its own burrows. However, in tighter, clayey soils they more often (perhaps exclusively) take over holes dug by other species (e.g., armadillo dens, holes dug by coyotes in search of rodents). Rose and Judd (1982; see also Judd and Rose 1983), however, reported that G. berlandieri does not construct its own burrows.

Birds (Class Aves)

22. Headstrom (1951) listed fewer than 20 species of birds to have nests located in burrows. Several species of petrels (Fork-tailed, Beal's, Black and Socorro Petrel, all occurring along the United States Pacific coast, and Bermuda Petrel of the West Indies) nest in burrows reaching maximum extent of about 3 feet; most such burrows are located in banks, bluffs and cliffs along the shorelines of islands (Headstrom 1951; Wingate 1978). Other birds utilizing burrows along the Pacific coast include the Marbled Murrelet (short burrow in bank or mountainside), Cassin's Auklet (2 to 4 foot long burrow beneath tree

*Personal Communication, Richard Franz, Research Associate, Florida State Museum, University of Florida.

roots or partially buried logs or stones), and the Rhinoceros Auklet (burrow 5 inches in diameter, 5 to 15 feet in length).

23. A variety of inland birds nest in burrows in banks and cliffs (Headstrom 1951; see also Collias and Collias 1984). The Elegant Trogon of southern Arizona deposits an egg in a bank hole about 18 inches deep. Belted Kingfishers of the western United States nest in holes, about 4 inches in diameter and usually between 3 and 15 feet in length, dug into banks of sand, clay or gravel. Burrows of Green Kingfishers are found in similar situations as those of Belted Kingfishers, but diameter is only about 2 inches and length about 2 feet. Bank Swallows place their nests at the end of a 5 inch diameter tunnel extending up to about 8 feet into the banks along lakes and streams in the western United States. Nests of Rough-winged Swallows similarly are located in burrows extending 6 feet or more into banks of clay, sand or gravel. Painted Redstarts of the American southwest nest in small cavities beneath stones projecting from banks in the vicinities of springs and waterfalls.

24. Probably the most highly-fossorial of the birds is the Burrowing Owl which occurs in arid lands of western North America and disjunctly in southern Florida (Robbins, et al. 1966). In most situations, these owls occur coincidentally with burrowing rodents such as Beechey ground squirrels (Spermophilus beecheyi), and prairie dogs, genus Cynomys (Coulombe 1971). In most cases, nesting and burrowing habits of Burrowing Owls seem to be examples of inquilinism, the phenomenon in which one species uses the shelter built by another species. Many studies suggest that these owls are incapable of digging their own burrows, and therefore are dependent upon burrowing mammals for homesites (e.g., Dawson 1923). Conversely, other papers (e.g., Goodrich 1945) report that Burrowing Owls can dig their own burrows. Thomsen (1971) states that they occasionally do dig their own burrows (by using feet and beak), but that more often they enlarge and improve existing holes. On occasion, Burrowing Owls apparently evict the original owners.

Mammals (Class Mammalia)

25. A tremendous proportion, perhaps the majority, of terrestrial mammalian species engage in some manner of burrowing activity. It is impractical, therefore, to present an exhaustive listing of burrowing species in a document of this scope. A representative cross-section of such mammals is treated in the following section according to the degree of fossoriality exhibited. Table 1 summarizes burrow characteristics and soil displacement for selected species of mammals.

26. Surface-scratchers. Many species can be considered merely as "surface scratchers" who do not dig burrows for nesting, resting or other such purposes, but simply dig shallowly to locate food or to cache food obtained elsewhere. Most tree squirrels are

Table 1.--Burrow characteristics and soil displacement for selected species of mammals. Figures are taken as published from the literature cited in the text. All measurements are approximate as considerable variation exists between individuals of any species.

Common Name and Scientific Name	Tunnel Depth	Tunnel Diameter	Tunnel Length	Amount of Soil Displaced
Hispid cotton rat *Sigmodon hispidus*	a few inches	2 in.	25 ft.	--
Prairie dog *Cynomys ludovicianus*	14 ft.	4 to 5 in.	109 ft.	0.17 m^3/ tunnel system
Thirteen-lined ground squirrel *Spermophilus tridecemlineatus*	4 to 46 in.	2 in.	20+ ft.	--
Columbia ground squirrel *Spermophilus columbianus*	30 cm	8.8 cm	18 m	1.3 tons/ha/yr
Mountain beaver *Aplodontia rufa*	shallow	4 to 6 in.	many feet	--
Muskrat *Ondatra zibethicus*	--	4 in.	6 to 10 in.	--
Eastern mole *Scalopus aquaticus*	3 to 35 cm	2.5 cm	185 m; 400 yards	--
Hairy-tailed mole *Parascalops breweri*	8 to 45 cm	5 cm	550 m	--
Southeastern pocket gopher *Geomys pinetis*	2 to 60 in.	2 to 4 in.	20 to 525 ft.	--
Plains pocket gopher *Geomys bursarius*	1 to 68 cm	6 cm	100+ m	84,000 kg/ ha/year
South Texas pocket gopher *Geomys personatus*	10 cm	10 to 13 cm	30+ m	--
Botta's pocket gopher *Thomomys bottae*	6 to 60 cm	2 to 3 in.	63.2 m	--
Northern pocket gopher *Thomomys talpoides*	--	--	--	11,250 kg/ ha/year

excellent examples of surface scratchers. Virtually all their digging produces small holes, usually only 1 or 2 inches deep, into which food (usually acorns) is placed or from which food is removed. Armadillos and many carnivores (e.g., coyotes, foxes, bobcats, etc.) likewise dig shallowly in pursuit of animal prey and plant food sources.

27. Intermediate burrowers. A second category of digging mammals includes those species which excavate shallow to moderately extensive burrows to be used for only a few aspects of their life histories (i.e., as sites for nesting, shelter, resting, hibernation, estivation, etc.). Many terrestrial rodents can be considered burrowers of this sort. Cotton rats (Sigmodon) and voles (Microtus and others) occur widely in North America. Although these rodents forage on the ground surface for various above-ground plant parts, they dig and maintain underground tunnel systems. For example, the hispid cotton rat (Sigmodon hispidus) digs a simple system of tunnels about 2 inches in diameter, and up to about 25 feet long located a few inches beneath the surface (Davis 1974). Such tunnel systems often are located beneath logs, rocks and other objects. Among the deer mice, the old field mouse (Peromyscus polionotus) is the most notable burrower; it produces often extensive tunnel systems in the sandy soils of the southeastern United States coastal plains (Blair 1951).

28. The various ground squirrels of family Sciuridae are notorious burrowers. Prairie dogs (e.g., Cynomys ludovicianus) occur in colonies of many individuals. Such a "town" in Mellette County, South Dakota, had an estimated population of 575 individuals occupying 139 burrows in an area of 107 acres (Sheets, Linder and Dahlgren 1971). Each burrow system examined was made of a series of complex passageways and chambers. Tunnels averaged 4 to 5 inches in diameter; system depth extended as far as 14 feet, and total distance of passages in one system was as great as 109 feet. For this town, burrow system length and diameter averaged 13 m and 13 cm, respectively, for a total of about 0.17 m^3 of soil excavated per system (King 1984).

29. Tunnel systems of other ground squirrels may also be rather extensive though usually less so than for prairie dogs. The thirteen-lined ground squirrel, Spermophilus tridecemlineatus, dig burrow systems having two or three openings, having about a 2 inch diameter, descending to depths of 4 to 46 inches, and having lengths of 20 feet or more (Davis 1974). The burrow of one Ammospermophilus interpres, the Texas antelope ground squirrel, extended for a distance of 9 feet into a cut bank and had a diameter of 3.5 inches (Davis 1974). Marmots similarly burrow into banks, cuts, berms and hillsides; burrows for Marmota flaviventris, the yellow-bellied marmot, achieve lengths of about 5 m (Frase and Hoffman 1980). In the Canadian Rocky Mountains, the Columbia ground squirrel (Spermophilus columbianus) burrows into silty and sandy soils, often with

considerable gravel content, at depths of up to 30 cm to produce tunnel systems averaging 18 m in length (Smith and Gardner 1985). Mean tunnel diameter is 8.8 cm. Columbia ground squirrels transport sediment to the surface at a rate of up to 1.36 tons per ha per year.

30. Mountain beavers (Aplodontia rufa) of the Pacific northwest are vigorous burrowers (Dalquest 1948). They produce large tunnels, 4 to 6 inches in diameter, which extend for many feet through the damp soils of the forest floor. Because many tunnels are shallow, cave-ins are common. Much of the soil excavated is transported and stored in unused portions of the tunnel system, or may be ejected from the system into piles containing nearly a cubic yard of earth and stones.

31. Kangaroo rats (genus Dipodomys) and pocket mice (genus Perognathus) range widely through the Great Plains, Great Basin and southwestern deserts. Virtually all of these rodents excavate some sort of burrows. Among these species, Dipodomys spectabilis, the banner-tailed kangaroo rat, builds perhaps the most extensive burrow system; associated with a complex network of undergroud passages and galleries are large earthen mounds, up to 4 feet in height, breached by up to a dozen openings (Davis 1974).

32. Some burrowing rodents exhibit semi-aquatic lifestyles. Muskrats (Ondatra zibethicus) may construct houses in the midst of a marsh or may burrow into the banks of canals, creeks, rivers, tanks, etc. Dens are located usually at the end of a 4 inch diameter tunnel that extends 6 to 10 feet into the bank; burrow entrances usually are below water level (Davis 1974). Nutria (Myocastor coypus) occur in much the same ecological situations as do muskrats. Their tunneling into banks produces passagways about 4 feet long and 8 to 9 inches in diameter. Beavers can produce very large burrow systems: Burrows along the "Rio Grande...were large enough to admit a man and 30 feet or more in length. Burrows as long as 150 feet have been reported" (Davis 1974). The round-tailed muskrat (Neofiber alleni) is a semi-aquatic, semi-fossorial, shallowly-burrowing rodent that occurs in marshy situations in Florida (Birkenholz 1963).

33. In addition to the aforementioned rodents, many species of carnivores and other mammals utilize burrows as dens. Usually, however, such dens are neither extensive nor abundant. Such dens may be built by the occupying carnivore (e.g., coyotes, foxes, etc.) or be modified from a previous occupant, frequently some species of burrowing rodent. Carnivores of the family Mustelidae (e.g., ferrets, weasels, badgers, etc.) might be considered the most fossorial of the North American carnivores. Their long-bodied, short-legged form corresponds to their mode of feeding - that of pursuing prey (e.g., prairie dogs, etc.) through the very underground tunnel systems built by the prey species. Hence, exclusion of the burrow-digging prey species likely will decrease the impact of predator

species.

34. Highly-fossorial burrowers. This final group of mammalian burrowers includes those species which conduct most aspects of their life history underground. The principal examples are moles (family Talpidae) and pocket gophers (family Geomyidae), small mammals which range over much of North America.

35. Virtually all species of moles inhabit regions with moist, sandy or loamy soils. The eastern mole, Scalopus aquaticus, illustrates the two types of tunnels that moles generally excavate (Lowery 1974; see Figure 1). Moles forage for insects and other invertebrates in shallow (only about 1 inch beneath surface) runs which usually are used but once; soil moved in the formation of such runs normally is displaced upwardly to produce a diagnostic ridge at the surface. Soil from the more permanent tunnels, maintained at depths of about 8 to 12 inches, is moved to the surface via vertical shafts and accumulates in characteristic mole mounds, each usually several liters in volume (Hickman 1984). Hickman's (1984) excavation of the complete burrow system of a 40 g Scalopus aquaticus in Central Florida revealed a system 185 m in length, about 2.5 cm in diameter, and with depth ranging from 3 to 35 cm. The deep tunnel of one mole in eastern Texas was about 400 yards long (Davis 1974)! Such tunnels often run beneath rocks, tree roots, or other obstacles. The hairy-tailed mole, Parascalops breweri, of northeastern North America constructs tunnel systems similar to those of Scalopus: The system of a hairy-tailed mole in New York ran 550 m in length with tunnel diameter of about 5 cm and depth usually between 8 and 45 cm (Hickman 1983; see Figure 2).

36. Pocket gophers are a group of subterranean rodents represented over most of North America, from southern Panama into the southeastern United States and, in the Great Plains and west coast, north to and beyond the United States-Canadian border. The family consists of about 40 species belonging to 8 genera. Most often they occupy in soils of high sand and loam content and of low clay content; moderate gravel content does not deter some species (e.g., genus Thomomys). Gophers rarely venture from the security of their burrow systems except for dispersal of juveniles from their birth sites or in search for mates.

37. Brown and Hickman (1973) excavated the tunnel systems of 40 southeastern pocket gophers (Geomys pinetis) in the sandy soils of Tampa, Florida, in an effort to determine the general design of their burrows: Burrow systems normally consist of one main linear tunnel (lengths ranging from 20 to 525 feet, average = 145 feet) with several short lateral branches (see Figure 3). Although most tunnels lie between 6 and 18 inches below the surface, some are as shallow as 2 inches or as deep as 60 inches. Tunnel diameter usually is only slightly greater than body diameter. Chambers containing food

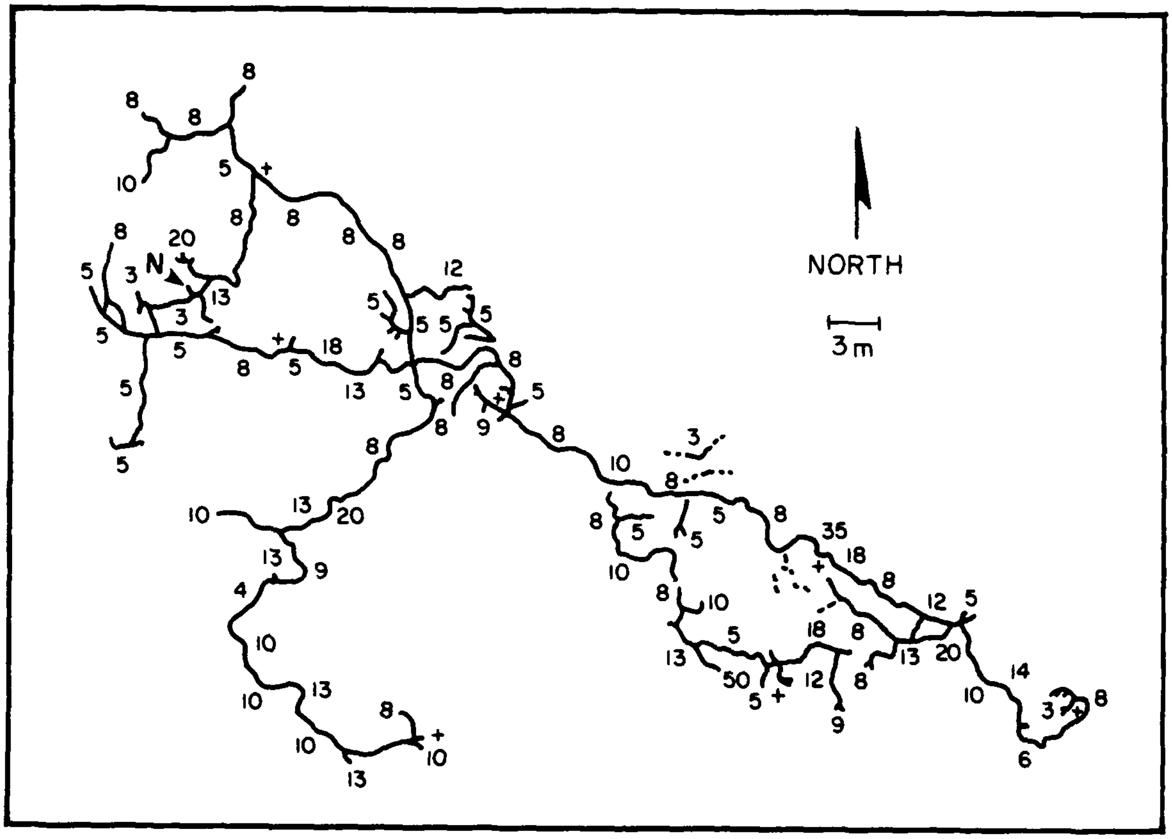

Figure 1. A completely excavated burrow system of a 40 g female Scalopus aquaticus from Hernando County, Florida, during December 1981. Oak tree forest on the left gradually opens over flat terrain into grassland, and eventually to open sandy areas to the right (crosses mark the position of trees; N indicates the position of the nests; dashed lines indicate plugged burrows; all depths are indicated in cms (modified from Hickman 1984).

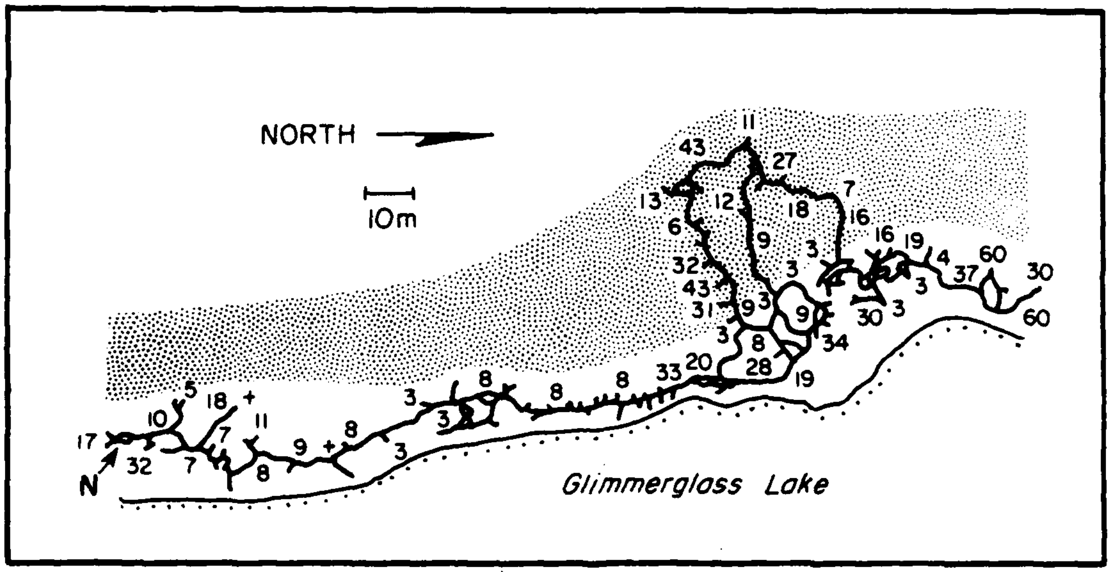

Figure 2. A completely excavated burrow system of a 30 g male Parascalops breweri from Oswego county, New York, during July, 1981. The nest was located one metre high from water level. An area of mowed grass in indicated by light stipple, crosses mark the position of trees, and N indicates position of the nest (modified from Hickman 1983).

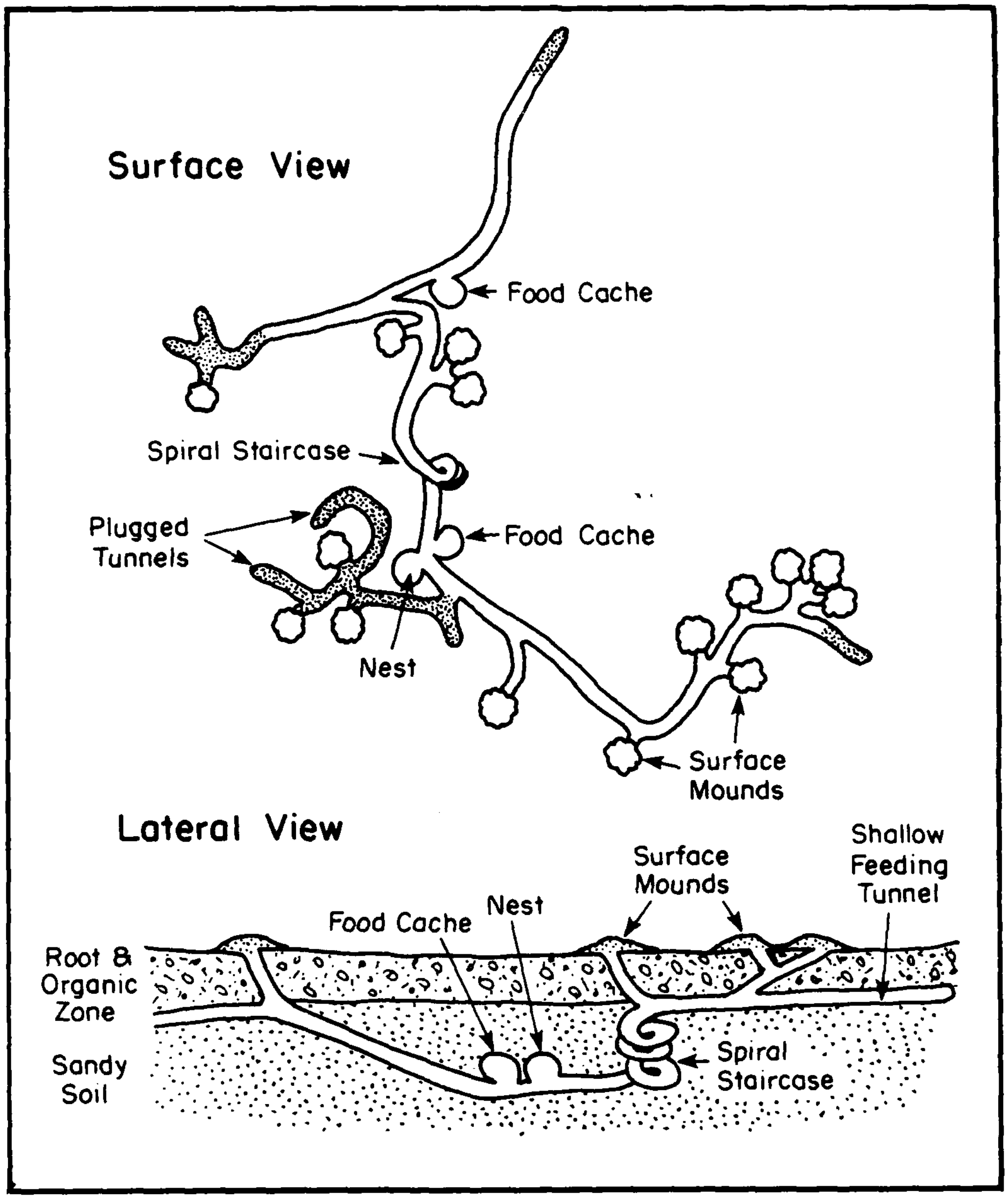

Figure 3. Diagram of a "typical" tunnel system of Geomys pinetis in surface and lateral views (modified from Brown and Hickman 1973).

caches and nests are normal components of such systems. Soil removed during tunnel excavation is deposited either (a) into abandoned shallow, lateral foraging tunnels and/or (b) onto the surface in mounds. The number of mounds per burrow system varies tremendously and is not a good indicator of extent of a tunnel system. Likewise, range observed in mound size is also great; mound diameter ranges from about 4 inches to about 4 feet and mound height between 3 inches and 12 inches.

38. The basic plan described above for Geomys pinetis seems to apply for most species of pocket gopher, although dimensions and other specifics vary by species. For example, the length of burrows of Thomomys bottae in Arizona averages 63.2 m (Reichman, Whitham and Ruffner 1982), whereas those in Texas occasionally exceed 150 m in length at depths of 6 cm to 60 cm (Davis 1974). The plains pocket gopher (Geomys bursarius) ranges over most of the Great Plains; average diameter of its burrows in Texas is about 6 cm, mean depth is 14 cm (extremes: 1 cm to 68 cm), and system length is 100 m or more (Davis 1974). Geomys personatus occurs in the deep sands of southern Texas where its tunnels tend to be situated about halfway between the surface and the water table, which is about 50 cm below the surface. This proximity to the water table often causes runways to be soppy from seepage. Burrows of G. personatus are 10 cm to 13 cm in diameter, are located about 10 cm subsurface, and are 30 m or greater in extent (Davis 1974). The giant pocket gopher (Orthogeomys heterodus) in Costa Rica digs systems with tunnels of 8 cm diameter located in an average depth of 8 cm (range: 6 cm to 10 cm; Sisk and Vaughan 1984).

39. From the preceding, it is apparent that pocket gophers move considerable amounts of soil, often during a short time. For example, one Geomys pinetis produced 62 mounds in one month, and another individual made seven mounds in less than 21 hours (Hickman and Brown 1973). Geomys bursarius can produce five mounds in 2 hours and 45 minutes (Kennerly 1964). Measurements of soil volume moved are available for some species. In a study of population ecology of gophers on the Texas coastal prairie, Spencer et al. (1985) determined that new mounds were formed at the rate of 60 mounds per ha per day (=0.92 mounds per gopher per day). Area covered and volume of average mounds were about 0.1 m^2 per mound and 3.0 liters per mound, respectively. Extrapolating this mounding rate over a year, about 57,000 liters of soil per ha (= about 84,000 kg soil per ha per year) would be brought to the surface. Further extrapolation indicated to those researchers that the entire study site would be covered (assuming no area covered more than once) by mounds in just over 4 years! A similar study addressed mounding impact for Thomomys talpoides in the shortgrass prairie of Colorado (Grant, French and Folse 1980): An estimated 3% of the ground surface is covered by gopher mounds (mean size = 0.12

m^2) annually. Each of the approximately 2,500 mounds produced per ha per year contains about 4.5 kg of earth, for a total of about 11,250 kg of soil annually brought to the surface per ha (= about 5 tons per acre per year). Corresponding information is available for several other species of pocket gophers (e.g., see Buechner 1942; Ellison 1946; Richens 1966).

40. Pocket gophers are thought to be one of many agents responsible for the North American version of the phenomenon known as "mima mounds," wherein grasslands in relatively flat situations become dotted by huge numbers of relatively regularly-spaced hillocks. Such mounds may have diameters up to 25 m, may be over 2 m high, and may occur in densities of up to 50 per ha (Cox 1986). Mima mounds are formed by the translocation of soil, over long periods of time...over the period of perhaps of thousands of generations, according to Dalquest (1948). Cox (1984), however, suggests that the process is more rapid; his experimental data indicate that an average mound (0.48 m high, 11.5 m diameter; volume of about 25 m^3) could be formed in about 108 years, assuming negligible erosion. Of direct bearing to the thesis of this report is that pocket gophers tend to have different responses to obstacles (e.g., rocks) on the basis of object size (Mielke 1977): Gophers dig around smaller pebbles (about 0.5 cm diameter) and pull them through the mound and deposit them on the surface of the mound. Gophers undermine stones of diameter greater than about 0.5 cm; these settle to from the cobble beds characteristic of mima mounds. Aten and Bollich (1981) remind us that about 30 different mechanisms have been reported for pimple mound formations. They suggest that such mounds are aggradational (rather than erosional) in origin. Further, they note that some pimple mounds harbor archaeological deposits.

Vertebrate Burrowers as Agents of Site Decay

41. The archaeological literature is replete with caveats regarding the role of certain vertebrate species in disrupting the stratigraphy of archaeological sites. Goodyear (1971) broadly cautioned that the work of animals (e.g., "earth-worms to rabbits and badgers") in materials decay processes must not be overlooked. Certain activities of non-burrowing terrestrial animals (e.g., livestock, etc.) also can promote site decay: Surface passage along the same route can destroy vegetation, thereby exposing soil to erosion by surface water with the result of gully formation (Pyddoke 1961). Surface trampling can cause substantial mixing of materials within the top 30 cm of the soil (Mathews 1965). Harris (1979) noted that downward movement of younger fossils into lower, older strata can result from fluid percolation and the activities of burrowing animals. Similarly,

Pyddoke (1961) implicated mice, rats, foxes, badgers, rabbits and moles as species whose burrows honeycomb the soil, thereby weakening upper layers and facilitating soil collapse.

42. Most research examining such processes of "faunalturbation" has focussed on invertebrate animals, especially on earthworms. Stein (1983) identified five means by which earthworms can disrupt archaeological sites: (1) Earthworms obliterate stratification by mixing materials from adjacent strata. (2) Objects can be buried, especially by surface-casting species which carry fine-grained silt from below to the surface. An experiment by Rolfsen (1980) determined that the burial rate can be nearly 10 cm per year. (3) The soil churning activity of earthworms can obscure the boundaries of adjacent strata. (4) Earthworms may selectively feed on certain plant materials (e.g., seeds) whose presence is important in the reconstruction of the paleobotanical assemblage. (5) Chemical composition of the sediments can be altered when excreta and other animal materials are mixed into the soil. An additional means by which earthworms confound stratigraphy is via localized collapse of overlying soil into burrows with the effect that objects properly positioned in higher strata will sink to lower strata, in one case at a rate of about 2 inches in 10 years (Atkinson 1957).

43. The effects of burrowing vertebrates as site decay agents apparently have not been studied extensively; Wood and Johnson (1978) provide a recent summary. Notable exceptions are studies by Rockwell (1980), Erlandson (1984) and Bocek (1986) which are discussed below. That is, perhaps, surprising considering the demonstrated importance of earthworm burrowing. Furthermore, it is common archaeological practice (at least in Florida) that initial prospecting involves examination of mounds of pocket gophers and gopher tortoises.* Franz noted that pocket gopher mounds tend to be better indicators of buried sites than do tortoise mounds because much of the tortoise digging is at depths below archaeological strata; pocket gophers excavate at shallower levels at which artifacts are much more frequently encountered. "Earth...thrown out by burrowing animals [e.g., moles] has not infrequently betrayed the existence of an archaeological site, for with the loose earth are expelled coins, potsherds, etc." (Pyddoke 1961).

44. At least two studies have addressed the role of pocket gophers (Thomomys bottae) in an archaeological setting. Erlandson (1984) recognized that the bimodal vertical distribution of artifacts in a California foothills site corresponded to the two depths at which these pocket gophers focus their subterranean activities. Rockwell (1980) reported that the majority of burrowing activity occurs bimodally at depths of 15 to 20 cm (level of most foraging tunnels) and 50 to 55 cm (level of nests, food caches and of chambers

*Personal Communication, Richard Franz, Research Associate, Florida State Museum, University of Florida.

housing feces). Rockwell (1980) concluded that a significant amount of shallow stratum soil (with associated cultural materials) can be transported via washing through tunnels or via subsidence to lower levels over time. Erlandson (1984) implicated Thomomys bottae as the primary agent of artifact redistribution (at an average rate of 5% per century). He further indicated that faunalturbation will lead towards homogenization of cultural deposits at any site inhabited by any type of burrowing animal.

45. Bocek (1986) presented a summary of effects that burrowing rodents can have on sites. Among those effects are that significant concentrations of non-cultural rodent bone can be found near the surface and near the 50 cm level. Additionally, at heavily disturbed sites, intrusive cultural materials may occur in lower sterile horizons, significantly below basal cultural deposits. Rodents also are important in vertical homogenization of materials: materials between 0.6 and 2.5 cm in size occur disproportionately near the surface (due to upward transport by rodents), whereas those greater than 5 cm cluster below the rodent zone (due to undermining and subsequent collapse). Bocek (1986) noted that rodent disturbance at the Jasper Ridge site (in Santa Cruz Mountains, California) probably had caused a 250% reworking of soils in the 1000 years since occupation, and concluded that, despite causing extensive stratigraphic disturbance, rodents have minimal effects on horizontal distribution of materials. I, however, contend that rodents can indeed cause significant horizontal redistribution of materials.

Non-Burrowing Vertebrates as Agents of Site Decay

46. For many of us, the mere mention of packrats immediately conjures images of a rodent nest containing sticks, bones, shell cartridges and a diversity of other objects. Also known as woodrats (genus Neotoma), these rodents occur widely through North America. They are normally not considered to be burrowers. Rather they build nests, or "houses," largely of twigs in caves, crevices, among rocks, among clumps of cactus, or among low-growing vegetation on the forest floor (Davis 1974). Their behavioral tendency to "sample" the area surrounding their homes by "packing" various plant and animal materials and artificial objects has been a great boon to the study of paleoecology. Much of our understanding of past botanical assemblages and paleoenvironments stems from the serendipitous preservation in woodrat middens of plant materials collected by woodrats (e.g., Van Devender 1987). Seeds and vegetative parts of a vast array of plant species, as well as fossils (bones and teeth) of more than 20 taxa of reptiles and amphibians, have been discovered in woodrat middens (e.g., Van Devender, Phillips and Mead 1977; Mead, Van Devender, and Cole 1983; Betancourt, Van Devender and Rose 1986). Porcupines

(Erethizon dorsatum) likewise are involved in collection of such materials (Betancourt, Van Devender and Rose 1986).

47. Taphonomists, paleontologists who study the mechanisms by which fossils are deposited, recognize the potential (in some cases the actual) role that modern organisms can play in deposition and reworking of fossils or cultural materials. Brain (1980) examined the bone collecting habits of the African porcupine (genus Hystrix), a species he suspects carries more bones to caves than does any other animal species. African porcupines are not burrowers; rather they normally locate their lairs in caves or rock crevices. For one den, 380 objects (bones, horns, etc.) were imported by porcupines over 12 years, an accumulation rate of about 32 objects per year. Brain (1980) determined that skeletal materials of antelopes collected by porcupines reflect the relative abundance of the antelope community. Porcupines seem to "prefer" some skeletal parts over others with the majority of bones and bone fragments weighing less than 50 g, although some bones or fragments weighed up to 750 g (about 1.6 pounds). The larger bones, however, are the ones more often gnawed. The bone-gnawing habits of these porcupines (and perhaps of other rodent species as well) seem to be concerned mainly with the continual need to wear their ever growing incisors which must be kept at a certain length for them to remain usable. Nutritional value of bone apparently is of only secondary importance.

48. Woodrats and African porcupines may seem to lie peripheral (for reasons of geography and of non-burrowing habits) to the thesis of this report. However, these rodents do redistribute and modify bone, activities that surely on occasion will lead to interaction with archaeological deposits. It is evident that the list of vertebrate species which might alter archaeological sites must be expanded to include some non-burrowing terrestrial species as well.

Conclusions and Projections of Impact on Newly Buried Sites

49. All four classes of terrestrial vertebrates include species which engage in some manner of burrowing, ranging from very shallow, occasional digging to construction of extensive deep tunnel systems in which the animal spends virtually its entire life.

50. The vertebrates which dig most extensively and which move the most soil apparently are the gopher tortoises (genus Gopherus), the insectivorous moles (family Talpidae), and a variety of herbivorous rodents, primarily the pocket gophers (family Geomyidae) and the prairie dogs and other ground squirrels (family Sciuridae). Clearly, future studies designed to investigate the role burrowing vertebrates in archaeological site decay must focus on these groups. However, any species which engages in any degree of burrowing potentially

can affect stratigraphic distribution of materials in sites: Even if an animal does not transport soil to the surface, simple tunnelling and undermining will almost certainly lead to subsidence and consequent downward movement of materials. It is evident as well that some non-burrowing vertebrates (e.g., woodrats, porcupines, etc.) can also be effective relocators of bones and cultural materials.

51. Generally, a terrestrial vertebrate species must already be present in an area to be of concern as an agent impacting a newly-buried archaeological site. This is particularly true for species of low dispersal ability (e.g., most ground-dwelling rodents, salamanders, frogs, toads, lizards, turtles, etc.). Larger vertebrates, such as carnivores that feed on the ground-dwelling species above, range more widely, and, thereby, would be more likely to find the newly buried site. However, these carnivores will be less likely to take up residence at or near the site if their prey species (e.g., rodents, etc.) are not present. Burrowing birds, however, are highly vagile and likely will locate such a site, and if substrate is suitable, may well make an effort to occupy. Occupation by swallows, kingfishers and other burrowing birds is most likely if the site is embedded in an embankment overlooking a body of water. Likewise, semi-aquatic rodents probably will be of concern only if the site is part of, or near to, the bank of a pond, stream or similar body of water.

52. The nature of the material used for burial is perhaps the major factor in determining whether burrowing vertebrates will invade and occupy the site. Most burrowing vertebrates require a friable soil - usually a mixture of sand, loam and perhaps gravel - which has an intermediate moisture content. A burial material of high clay content probably will not be invaded by most types of burrowing vertebrates. Furthermore, the thicker the layer of overburden, the less likely are burrowers to enter the site proper. Extremely high or extremely low soil moisture content in combination with non-friable soil in thick layers likely will discourage most burrowing vertebrates.

53. The preceding comments probably apply for most conceivable environmental settings, whether upland or lowland. The particular species of vertebrates involved, of course, will vary by habitat and geographic location. Even so, some suite of burrowing species occurs in virtually any habitat. Current knowledge suggests deep burial of a site with overburden not conducive to burrowing will significantly reduce the impact of burrowing vertebrates on a site. The depth and manner of application cannot be known without experimentation. Also, treatments that discourage some species may well encourage other species to reside near and/or in the site and thereby degrade the site in ways not previously envisioned.

Suggestions for Further Research

54. There is a "critical lack of quantified data...concerning the effects of various types of faunalturbation and other site disturbance factors upon distributions of archaeological materials" (Erlandson 1984; see also Wildesen 1982). The research strategy for resolving this problem should begin with description of burrowing ecology and behavior of species occurring now (or in the historic past) in the vicinity of archaeological sites of interest. Such information obtained for one species of burrower (e.g., a pocket gopher) will probably apply generally to all pocket gopher species. But no two species of pocket gophers (or of prairie dogs or of ground squirrels or of tortoise, etc.) have identical ecologies or ethologies. Hence, each species having potential impact on a particular site should be separately examined.

55. Initial descriptive studies of impacting species should produce information on topics including (but not restricted to): (a) design of burrow system including depth, diameter of tunnels, etc., (b) soil requirements including relative content of sand, loam, etc., moisture content, etc., (c) role of water table level in determining burrow characteristics, (d) geomorphic effects such as amount of soil moved, dispositon of excavated soil, importance of subsidence, etc., and (e) behavioral tendencies of species to actively relocate objects such as rocks, bones or cultural materials.

56. Such descriptive studies will raise questions that can be evaluated experimentally. For example, does the species preferentially relocate certain materials? If so, what is the pattern and rate of redistribution? What is the effect of population size and density of the impacting species on the rate of site decay? How can such species be excluded from archaeological sites?

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LIMNOLOGY AND THE PRESERVATION OF ARCHAEOLOGICAL SITES

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Natural Lakes

1. Except for the few lakes in closed basins with no natural outlets, lakes maintain their water level over fairly long periods of time. Year-to-year changes of a few feet may occur, but changes of the magnitude of several meters are not common. The region defined by these changes and by the upper limits of storm waves would be well defined, and it would seem to be unlikely that archaeological structures would be built within this zone. Any temporary campsites would be destroyed by the next storm. Decreases in water level of natural lakes would not seem to be a preservation problem. Rarely, geological events can cause changes in the lake outlet which could cause a rise in lake level. In these cases, sites formerly well out of range of storm waves may be impacted. The primary influences would be the physical destruction by the waves and any bank slumping caused by the formation of the new shoreline. A new zone of frequent wet-dry cycling would also be established, which could enhance the deterioration of some materials. The energy of a storm shore is enormous, and the sheltering of any structures in this zone would be very expensive.

Reservoirs

2. Natural lakes may have their outlets artificially raised, or a dam may be built which creates a new body of water. In both of these cases structures formerly well out of range of the water may be completely submerged. These artificial water bodies are usually built for water supply and/or flood control, and the operation of the reservoirs for either of these purposes results in a very large fluctuation in water level. This causes the formation of a very wide shoreline band in which wave action and alternate submergence and emergence occur. Preservation of sites within this zone would be, as noted above, very difficult.

Open water

3. The energy of wave action decreases very rapidly with depth, and structures a

meter of two below the lowest water level would not be exposed to large forces. Materials would be degraded or destroyed by solution or by chemical or biochemical action. Solution will continue, limited only by contact with the water and the solubility constants involved. Chemical and biochemical activity will be determined by a number of factors:

4. Temperature. Chemical reactions. and particularly biochemical reactions, will proceed much faster in warmer water. In the U.S., most lakes and all but the largest reservoirs will circulate all the way to the bottom in the winter. If the winter is cold enough to form ice, the water will be near 4 deg C except right near the ice, since this is the temperature of maximum density of water. In the southern part of the country the minimum temperatures will be between 4 and 10 deg C, depending on the latitude and the particular winter. In the summer the bottom temperature will depend upon the circulation characteristics of the particular body of water. In the north the deeper water may remain near 4 deg C if the lake is deep enough to allow density stratification. In deeper southern lakes the bottom water will usually be a few degrees above the winter minimum. In lakes at all latitudes, the surface water temperature will track the general climate. If the lake is too shallow to stratify, this would apply to water at all depths. The picture is more complex in reservoirs. Many reservoirs have outlets below the surface, sometimes at several levels. If there is a regular discharge from one of the deeper outlets, the colder deep water may be discharged and the bottom temperature will be higher than in a lake at the same latitude.

5. Oxygen. The presence or absence of oxygen will have a very great effect on the deterioration of materials. In the presence of oxygen a great variety of bacteria and fungi can function, and deterioration of organic materials can be rapid. In the absence of oxygen the biological populations are dramatically reduced, and organic materials can persist for long periods. Oxygen is almost always abundant in the well mixed surface waters of lakes and reservoirs. Only in the presence of gross organic pollution or during special circumstances in very productive lakes is the surface oxygen depleted, and then the condition does not persist. If the body of water stratifies, the oxygen content of the deeper water will depend upon the biological activity. If little organic material sinks into the deep water there may be no significant decrease in oxygen through time. As the amount of organic material increases, the oxygen demand increases, and the oxygen level will drop. In productive lakes or reservoirs the bottom water may become anaerobic before the summer is over, and the decomposition rate decreases drastically. Only in those rare lakes where the bottom water never mixes will the water remain anaerobic the year round. Thus, any materials in lakes and reservoirs will be exposed to oxygenated water, and the accompanying decomposition, for at least part of every year.

6. Chemical reactions. The variety of possible chemical reactions is far too great to

summarize here in any coherent fashion. Problems with individual chemicals would have to be followed up in texts such as Aquatic Chemistry by Stumm and Morgan (1981) or Chemical Processes in Lakes (Stumm 1985).

Sediments

7. Sediments are deposited continuously, with the amount of inorganic material dependent primarily upon the rate of import with runoff. Shore erosion can also contribute significantly in some cases. Organic material can be contributed from the runoff or from the internal primary production of the lake. The extent to which water is exchanged between the sediments and the overlying water depends primarily upon the grain size of the sediments. In gravel or coarse sand and with little silt, oxygen may be carried down several centimeters. In silty material, the oxygen all will not penetrate significantly. At some depth in every sediment, the rate of respiration will exceed the rate of oxygen import, and the sediments will become anaerobic, whether the overlying water contains oxygen or not. In aerobic sediments, decomposition will proceed much like it would in oxygenated water. In anaerobic sediments, decomposition is greatly retarded, and organic materials may persist for long periods of time. If materials for preservation could be covered in high organic content, fine grained sediments, and if they were in water sufficiently deep to have little wave action, they might be preserved for extended periods of time.

National Reservoir Inundation Study

8. Some of the topics discussed above have been addressed in the National Reservoir Inundation Study (Lenihan, et al. 1981a). I will comment on the sections which have a limnological component. For the benefit of those who do not have access to the National Reservoir Inundation Study (Lenihan, et al. 1981a, 1981b), the report's complete Executive Summary has been attached at the end of this paper.

Volume I, Summary

9. Observation #4. This section of the Executive Summary covers fundamental problems very well.

10. Chapter 3, Reservoir Processes. This chapter is an excellent coverage of limnological processes in reservoirs. It covers all of the topics in some detail. One quibble is the incorrect definition of "fetch" as the surface water area over which the wind blows, rather than the correct definition as the length of open water over which the wind blows. This chapter is an excellent source of limnological information as applied to preservation problems, and will be a more useful source than general limnological texts except where more detailed investigations of some of the processes is desired.

11. The remainder of the Summary presents conclusions and commentaries from specific Technical Reports. Rather than attempt to review the Summary, I will comment on the relevant Technical Reports themselves, which are contained in Volume II of the Final Report. These reports should be read before basing actions on the summary information.

Volume II, Technical Reports

12. Technical Report 3. This report is entitled "Laboratory Studies of Differential Preservation in Freshwater Environments" (Lenihan, et al. 1981b). In this study, several categories of materials (ceramics, lithic, wood, shell, seeds, bones and pollen) were submerged for one year in solutions of the eight most common freshwater ions. The chemicals were used at two strengths, one equal to the median concentration for U.S. reservoirs, and one at 20 times this strength. A series of pH levels was also used. Effects were evaluated by observation, weight loss, compression tests, x-ray diffraction, electron microprobe, atomic absorption and neutron activation analysis, as appropriate for the material concerned. The samples were changed to fresh solutions twenty times during the year in an attempt to minimize the bacterial action and evaluate only inorganic chemical effects. The 20x concentrations were intended to simulate longer exposures.

13. This is a good first step. General levels of effect were established and evaluation procedures themselves evaluated. It is not the definitive study from which conclusions on effect and treatment can be taken, it does provide a basis for the design of more definitive studies. Longer exposure times must be used. The validity of increased concentrations as a realistic simulation of increased exposure time must be established before this precedent can be relied on. The assumption is made that effect is a factor of concentration. The hypothesis that chemicals present in smaller amounts do not have a significant role must also be demonstrated. If it is indeed relevant to separate the chemical from the biochemical, a more definitive procedure than solution renewal must be devised. In any event, the effects of the biological component must also be evaluated. Deionized water was used as a control solution. Admittedly the problem of control is complex, but there will surely be problems with leaching into the deionized water. Mean U.S. water would seem to have been a better control!

14. Technical Report 6. Report 6 is entitled "Field Studies of Differential Preservation in Freshwater Environments: Brady Creek Reservoir, Texas; Clayton Lake Reservoir, Virginia; and Virginia Polytechnic Institute and State University" (Lenihan, et al., 1981b). This study was designed to extend testing from the laboratory, as reported in Report 3, to field conditions. The study was beset by problems in design and execution. The time periods were short (four to eight months), procedures were not identical between

reservoirs, chambers designed to exclude biological activity failed, and the culture techniques used to evaluate microbiological populations are known to give results which have little relationship to the actual bacterial flora.

15. Some good preliminary data were obtained about effects of sediments on deterioration, but these came from laboratory experiments in which the sediments were collected in buckets and brought to the laboratory for the testing. The paper provides some basis for the design of future experiments.

16. Technical Report 7. "Preliminary Experiments in the Structural Preservation of Submerged Anasazi Units" is the title of Report 7 (Lenihan et al., 1981b). This is an excellent study! Actual problems resulting from the limnological processes previously discussed are described, along with the attempts to alleviate them. Problems of shore energy, depth of inundation, solution and preservation are covered in some detail.

Executive Summary of the National Reservoir Inundation Study

Much confusion has surrounded the question of inundation, especially its impact on archaeological resources. While some people have argued that everything about to be flooded should be left alone (to serve as a data bank for the future), others have said that anything about to be flooded should be excavated (to save it from possible destruction). Often, both viewpoints would be found in Environmental Impact Statements generated within the same agency. Dialogue on the subject was degenerating to partisan rhetoric, with archaeological contractors arguing for extensive site excavation as the only viable mitigation tool and reservoir managers defending the preservation of sites through flooding.

In 1975, four Federal agencies decided to resolve the conflict through intensive research. They proposed the formation of the National Reservoir Inundation study in hopes that it would answer two questions: In what way does the construction of a reservoir affect the archaeological resource surrounding it? And, how can the effects of inundation on archaeological resources be mitigated?

The National Park Service archaeologists who became the Inundation Study's core team did not report to construction agency officials and were not involved in reservoir salvage contracts; thus they had minimal personal bias regarding the outcome of the study. From this perspective, they were able to make reasonably objective observations on the issues and have come to the

conclusions listed below. These are purposefully couched in general terms, for specifics would require an unwieldy amount of qualifying statements.

Observation #1: The overall effects of reservoir inundation on archaeological resources in any given drainage area are unquestionably detrimental in nature. The subjection of a resource base that is highly sensitive culturally, such as archaeological sites in a river drainage, to the radical environmental changes incurred by inundation results in large-scale destruction of data-bearing elements of the resource. Seeing the inundation process as a means of creating data banks for the future has limited utility in light of the impacts that develop and the subsequent loss of access to the data base.

Observation #2: The traditional response of the archaeological community to the threat of inundation is often ill-conceived and parochial in nature. Conducting large-scale, site-specific excavations on the basis of a priority listing of the "most important" sites leaves much to be desired and is happily also coming under fire within the discipline itself. Much more attention should be focused on the intersite environmental data base which is the aspect of the human behavioral record that is most susceptible to devastating impact. Additionally, archaeologists should devote much more attention to the overall susceptibility of impacts to different elements in the archaeological record instead of assuming that inundation affects archaeological values equally. Research proposals for mitigation should show a greater interest in and (sic) understanding of reservoir processes and the consequences for different aspects of the archaeological record.

Observation #3: Site protection is a viable alternative to the "excavation only" syndrome, but only in very specific circumstances. Rarely should preservation be seen as an answer in itself. Rather it should be accompanied by partial site excavations since some of the more vulnerable elements of the data base will almost always be lost. Both resource managers and archaeologists should also understand that site protection is rarely a less expensive option than field testing and limited excavation. This myth has caused much misunderstanding among both communities. What is often not considered is that an indefinite commitment to preservation involves not only major initial expenses but also an indefinite commitment to maintenance of the preservation mechanisms selected.

Observation #4: There is a critical lack of understanding of the

importance of reservoir zones with regard to differential effects on cultural resources. The deep-water zone is the least susceptible to most impact phenomena. It also, however, is the area that will present most problems to future researchers due to loss of access. Attempts at preservation will be most workable in this zone aside from the accessibility question. The most critical impact zone is the area subjected to shoreline fluctuation of the water level and wet/dry cycling. The most complete destruction can be expected here. The zones subjected to occasional flooding during high-water periods or those outside of the flood pool, however, are also potentially high-impact areas. Inundation Study research has demonstrated that the problem of human vandalism is extremely severe in those zones which are often considered to be the least affected by many researchers.

Observation #5: Postinundation managerial action must play a much larger part in the mitigation process. Whatever strategy towards mitigating impacts to archaeological resources is taken during the preimpoundment period, the obligation to intelligently manage and protect these values does not evaporate when the dam is built and the reservoir is functioning. It is given that, in almost all cases, many sites will not be excavated as part of a mitigation plan. When significant cultural resources remain intact to be subjected to flooding events, a serious attempt should be made through managerial action to create an environment most conducive to their survival. This may involve restricting areas to dredging operators or strengthening protection patrols in areas where archaeological sites at pool level are made more accessible to the public due to boating activities.

Observation #6: Communication between reservoir planning and construction personnel and archaeologists should be greatly increased. There are points in the reservoir construction process where increased dialogue and commitments may result in increased protection of resources at reduced expense to the taxpayer. One point is during the preauthorization planning phase where the release of funds for preliminary archaeological inventory could eliminate potentially serious impacts through avoidance. Another time that communication should be much greater is during the creation of the mitigation plan. Archaeologists rarely consult in depth with reservoir scientists about reservoir processes that will come into play in the areas where they plan to conduct archaeological research. This report should provide a jumping-off point to the archaeologists for relating the finding of

this study to their particular reservoir impact mitigation problems. It is most useful, however, when accompanied by dialogue with hydrologists, soil scientists, and structural engineers. Communication between archaeologists and managers during the operation and maintenance phase is also too rare an occurrence. Valuable insights can be gained regarding the presence of archaeological sites in relation to high-energy beach zones, susceptibility of the soil matrix in which sites are located to erosion, possible means of protection, etc. Such communication is a two-way street, and it should be noted that the archaeologist is not the only one who benefits from this exchange. A greater sensitivity to the nature, fragility, and problems associated with cultural resources can only benefit a reservoir scientist or manager and could well be incorporated as a part of their on-the-job training.

In as concise an outline as possible, the higher level manager should be made aware of several overall conclusions of the Inundation Study:

1. Reservoir construction due to its nature involves impacting the most culturally sensitive land areas in the nation. Drainages in prehistoric and historic times have been the loci of all major human activity patterns in the New World.
2. The Inundation Study has shown that these resources are unquestionably adversely affected from the reservoir construction process.
3. Inundation Study results have definitely indicated that different archaeological values are differentially affected by inundation.
4. Existing mitigation plans are often conducted without proper attention being paid to differential impacts on the basis of reservoir zones.
5. Site protection and preservation is a viable option in some circumstances, but it cannot be expected to result in significant savings over site excavation or sampling.
6. Archaeological concerns should be worked into the construction process earlier than they have been. A model for rethinking approaches to mitigation is offered in Volume I (Chapter 5) of this report.
7. Communication must be improved between archaeologists and reservoir construction specialists. This might be effected through the creation of formal training programs coordinated by construction agency archaeologists.
8. Steps should be taken to ensure that archaeological considerations are not abandoned after water has been impounded. Managerial action taken during

the operation and maintenance phase can be critical to preservation of a significant representation of the resource base.

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LOGIC-BASED QUALITATIVE SITE DECAY MODEL FOR THE PRESERVATION OF ARCHAEOLOGICAL SITES

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Introduction

1. Archaeological sites and engineering projects often come into conflict whenever a site is to be destroyed or disturbed by a proposed engineering project. Many federal, state and local governmental organizations with engineering responsibilities are required to protect the Nation's archaeological resources to be impacted by engineering projects. The conflict between archaeological sites and engineering projects can be subdivided into the following three general classes: 1) Projects requiring excavation: In cases where the engineering project requires excavation, the archaeological site must be excavated and the data in the site recorded to be preserved. 2) Accelerated natural processes: In cases where engineering projects have altered a natural geological system, such as a stream's response to a dam, acceleration of the natural processes may threaten a site, leading to a need to provide site protection against the attacking natural process. Archaeological site protection must be designed to respond to the active natural process. 3) Site burial or inundation: In cases where site disturbance amounts to burial below fill or inundation, it is often preferable to bury the site rather than to undertake a costly and limited site excavation project that removes the materials and destroys the site relationships.

Archaeological Sites

2. From an engineering perspective, an archaeological site can be viewed as an assortment of components (artifacts) that have a spatial relationship (context). To the archaeologist, a site is the smallest unit of space that is fairly continuously covered with the remains of former occupation associated with a single unit of settlement (Willey and Phillips, 1958). Gould (1988) points out that the word occupation has two quite different meanings in archaeology: 1) describing specific activities such as trade, skill or economic pursuit, and 2) related to physical space where people reside or perform various activities.

3. Gould (1988) defines three spatial relationships associated with archaeological sites. Geographical relationships describe the spatial context between clusters of artifacts

and features and their relationship to other clusters. To interpret a past culture, the relationship between clusters and their interconnecting links is as important as the data contained within a specific cluster. Stratigraphic relationships are used to describe the chronological and behavioral interpretation of past cultures and are based on the "law of superposition". Of major concern in the interpretation of a site is the question of how much of the chronological data based on site stratigraphy reflects past human activity and how much reflects post-formational alteration. Ethnographic relationships relate human occupation and activities to the cultural characteristics of the site. Such site characteristics and uses as a "kill site", where a large animal was killed and butchered, versus a "food processing site", where food is processed and prepared for daily use by the community, are examples of ethnographic relationship. The "kill site" is occupied only once and most implements and tools are removed while the "processing site" is used daily and tools and other artifacts would be stored near this site.

4. Carlson (1988) classifies ethnographic sites into two major classes, habitational sites and special function sites. Habitation sites, including seasonal camps, permanent settlements, and towns and cities, are occupied by whole family groups for some period of time. Special function sites, including hunting and gathering sites, mining sites, cemetery sites, ceremonial sites, and in-transit sites, are occupied for only a short period of time, or by only part of a family group or select members of the community.

5. The clusters of site components within the context of a site's spatial relationships are the artifacts, features and ecofacts that make up the total site. Hamilton (1988) defines archaeological data to include:

a. Artifacts: objects manufactured or modified by humans which may be made of animal bone and horn, shell, plant materials, lithics, ceramics and pottery, and metals;

b. Features: artifacts that cannot be removed from the ground such as post holes, fire pits, burial mounds, trails and mine openings;

c. Structures: usually residences, buildings or temples, standing above the ground surface, and occasionally, building sites that can be identified from patterns of post holes and foundation remains;

d. Ecofacts: the remains of food such as bones, plants and seeds; and

e. Human remains: the direct remains of humans, including skeletal parts, fecal matter, and hair.

6. An archaeological site, then, consists of the patterned distribution of artifacts, features, and ecofacts in three-dimensional space and time. A site to be protected or

preserved must incorporate preservation of both the components and their spatial relationships.

7. The workshop concluded that each of these components and spatial relationships reacts differently to changes in the physical, biological, and chemical environment surrounding the site. It was also concluded that the basic scientific information needed to develop a quantitative site decay model was not available at this time. However, the workshop was able to develop a decay matrix that could be utilized as a qualitative site decay model and applied until further investigation into the physical, biological and chemical processes affecting the preservation of archaeological sites becomes available.

8. To develop a model that could be used to protect and preserve an archaeological site by burial, the physical, chemical, and biological conditions that will develop upon burial must be known. Because the site is an assortment of components having a spatial relationship, changes in the site's environment can accelerate the decay of some components while enhancing the preservation of others. Thus, site protection and preservation projects must be designed to produce the desired beneficial environment. Table 1 lists the general decay effect, in descending order of their significance, of the physical, chemical, and biological factors on an archaeological site.

Table 1

Relative Significance of the Site Environment on the Decay of an Archaeological Site, Listed in Descending Order of Significance

Most Severe	Wet-Dry and Freeze-Thaw
	Wet Aerobic
	Compression
	Macroorganisms
	Freeze
	Wet Anaerobic
	Acidic Conditions
	Microorganisms
	Movement
	Basic Conditions
	Thaw
Least Severe	Dry

9. The qualitative decay model for the design and preservation of a site must be carried out as a cooperative effort between the engineer, geologist, soil scientist and archaeologist. To insure that the specific components or relationships at a site are protected, the archaeologist must identify the critical components and their relationships,

and the engineer, geologist and soil scientist must then design the burial with conditions capable of enhancing the preservation of the site components.

Qualitative Site Decay Model

10. The matrix shown in Figure 1 summarizes the effects of post-burial change on the preservation or decay of the components of an archaeological site. The influence of physical, biological and chemical processes on the decay process are discussed in the following paragraphs.

11. Significant physical processes identified during the workshop include: compaction/compression, freeze/thaw, movement, and ground-water conditions. Compaction and compression processes act to break brittle artifacts or displace components and destroy any geographic relationships. Freezing or freeze-thaw cycles act to break apart artifacts susceptible to freezing or disrupting spatial relationships through frost heaving. Movements within a site also break artifacts and disrupt associations. Large scale movements, such as slope failures, are a major concern for sites to be buried, since these processes completely disrupt spatial relationships through the translocation of artifacts.

12. Ground-water conditions are important physical factors which have a direct impact on the chemical and biological environment developed within a site. A ground-water regime that seasonally varies from wet to dry, such as along the shore of a lake, enhances the chemical decay of a site. A site within the shore zone of a reservoir is most severely impacted because the physical, biological, and chemical processes of decay are accelerated in the wet-dry conditions of this zone. It is believed that sites within the shoreline zone should be excavated and documented rather than buried.

13. Changes in the local climate which increase the humidity generally accelerate the dec of any exposed site component. These changes, often brought about through the construction of an open body of water, should be recognized and incorporated into any site preservation project. Changes to a drier climate tend to enhance the preservation of an exposed component.

14. The primary chemical processes identified by the workshop are the oxidation/reduction and pH characteristics of the buried site. Chemical factors have the greatest impact on the components making up any site. Unfortunately for site preservation, the various components react differently to changes in the chemical environment.

15. Continuously wet and anaerobic environments enhance the preservation of bone, shell and plant matter, and accelerate the decay of all other site components and spatial relationships. A continuously wet, aerobic environment accelerates the decay of all

SITE COMPONENTS

PROCESSES	ANIMAL BONES	SHELL	PLANTS	CHARCOAL	CRYSTALLINE LITHICS	GRANULAR LITHICS	CERAMICS	ARCHAEO. FEATURES	SOIL ATTRIBUTES	METALS	CONTEXT	ISOTOPE CONTENT	TOPOGRAPHY
ACID ENVIRONMENT	A	A	E	N	N	A	N	N	A	A	N	A	N
BASIC ENVIRONMENT	E	E	A	N	N	E	N	N	A	A	N	N	N
DRY (CONT.)	E	E	E	E	N	E	N	N	N	E	N	E	N
WET ANAEROBIC(CONT.)	E	E	E	A	A	A	A	A	A	A	N	A	A
COMPRESSION	A	A	A	A	N	N	A	A	A	N	A	N	A
MOVEMENT	N	N	N	A	N	N	N	A	A	N	A	N	A
WET-DRY	A	A	A	A	A	A	A	A	A	A	N	A	A
MICOORGANISMS	A	N	A	A	N	N	N	N	N	A	A	A	N
MACROORGANISMS	A	A	A	A	N	A	N	A	A	N	A	N	N
WET AEROBIC	A	A	A	A	N	A	A	A	A	A	N	A	N
FREEZE-THAW	A	A	A	A	A	A	A	A	A	N	A	A	A
FREEZE	A	A	A	A	N	A	A	N	E	N	A	E	N
THAW	N	N	N	N	N	A	N	N	A	N	A	A	N

E = ENHANCES PRESERVATION

A = ACCELERATES DECAY

N = NEUTRAL OR NO EFFECT

Figure 1. Logic based archaeological component decay and preservation matrix, which relates physical-chemical-biological processes to post-formation changes of specified site components.

site components except crystalline lithics. These conditions do not enhance the preservation of any component or spatial relationship of a site. A continuously dry environment enhances the preservation of all site components and relationships.

16. An acidic environment enhances the preservation of plant material and accelerates the decay process, or has no effect on other site components. Basic or alkaline environments enhance the preservation of bone, shell, and granular lithics, while accelerating the decay of plant material, soil attributes, and metals.

17. Significant biological processes identified by the workshop include microorganisms, macroorganisms (burrowing animals), and plant roots (Wicksten, 1988; Wilkins, 1988). The creation of an environment that increases the number of microorganisms accelerates the decay of bone, plant material, charcoal, isotopic content, metals, and site context but has little effect on shell, lithics, ceramics and site relationships.

18. Macroorganisms, especially burrowing animals, have a direct physical impact on a site through their burrowing activity. In addition these organisms tend to eat or chew on the site components, thereby accelerating the decay of a site.

19. Plants, especially large trees, have a physical impact on a site by mixing the site context with their roots. Significant mixing of the site context can occur whenever a tree is blown or pushed over. Special care should be exercised during preliminary clearing operations of a site where archaeological remains may be present. In addition, trees can induce biochemical decay near plant rootlets where active chemical reactions take place.

Recommended Procedures for Site Preservation

20. The qualitative site decay model developed during the workshop can be utilized as a planning and design tool to evaluate the potential of providing protection to an archaeological site through burial. Much of the basic technology needed to evaluate the potential impact of burial is available within the United States Army Corps of Engineers. Details of the actual impact of burial, however, have not been determined.

21. The initial step in the planning, design and evaluation of a site burial project lies with the preliminary archaeological investigation. The specific characteristics and components of the site to be protected must be defined. The decay matrix is then consulted to select the desired environmental change to be induced through burial. If the site contains a complex mixture of components, environmental conditions that enhance preservation may be limited to a few alternatives. For example, a site containing both shell and plant remains must be maintained at a neutral pH and either continuously dry or continuously wet and anaerobic for preservation. Increases in either acidity or alkalinity

will accelerate decay of both shell and plant material. If an environmental condition cannot be created to enhance the preservation of non-compatible components, it will be necessary to define those components to be protected and those components not to be protected. If this distinction cannot be made or if it is unacceptable, site burial is not the best preservation technique.

22. Once the site components have been defined and the desired environmental conditions for preservation identified, the engineers and scientists must evaluate the site to determine the existing physical, biological and chemical conditions. Design concepts are then developed and evaluated to determine if the desired environmental change will occur. If the desired conditions can be generated, then the design concept is evaluated with respect to the cost of the proposed burial project. If the design is economically favorable and the environmental change will enhance site preservation, then the project can be implemented.

23. When possible, sites that have been buried for preservation should be monitored to determine that the desired environmental changes have taken place. A monitoring program insures against any unforseen or unpredicted conditions that may accelerate site component decay.

Example of the Model Use

24. Assume that an archaeological site, situated along the coastal zone in a humid climatic region, has been surveyed by the archaeologist and found to contain artifacts and ecofacts composed of pottery, made with calcareous clays, and shell, and site features including fire pits and post holes. A proposed coastal road fill is to cross the site. A review of Figure 1 determines the following preservation conditions:

Environment	Shell	Pottery	Features
Acid	A	A	N
Basic	E	N	N
Dry	E	N	N
Wet Anaerobic	E	A	A
Compression	A	A	A
Movement	N	N	A
Wet-Dry	A	A	A
Microorganisms	N	N	N
Macroorganisms	A	N	A
Wet Aerobic	A	A	A

A = Accelerates decay
N = Has neutral or no effect on decay
E = Enhances preservation

25. This summary shows that the desired environmental conditions that enhance or have a neutral effect on preservation of the shell, pottery and site features are a dry and/or basic environment. This would suggest that limestone or shell materials (carbonates) be used for the fill section that crosses the site. Note that compression of the site will accelerate the decay of all desired site components; therefore, a geotechnical design should include an analysis of the potential settlement below the fill to minimize the compression and movement within the site. Care should be taken to design the fill to limit burrowing of microorganisms into the site. With proper design of the fill section and the selection of materials that produce the desired geochemical environment, it is possible to protect and preserve the site without a costly archaeological excavation.

Conclusions

26. The workshop concluded that it would eventually be possible to develop a quantitative archaeological site decay model. However, the model would be extremely complex due to the following factors:

a. Site component variability: archaeological sites are composed of individual items (artifacts) and their spatial and temporal relationships generate a large number of independent variables.

b. Physical variability: archaeological sites are situated in all physical environments and sub-environments throughout the globe, creating an enormous number of dependent variables.

c. Biological variability: biological interactions within a site are related to the physical environment; chemical and to the spatial distribution of numerous impacting organisms.

d. Chemical variability: although the chemical composition of the site components and the geochemistry of a site environment is relatively well known, the complex physical and organic chemistry processes are dependant upon the physical and biological environment and conditions.

The work required to generate a generic, quantitative site decay model is felt to be both excessively complex and economically unrealistic. A more reasonable approach to the problem of protecting archaeological sites is to develop a logic-based, qualitative decay model for a specific site or suite of sites that will potentially be impacted by an engineering project. If this approach is followed, the site decay matrix developed by the workshop can provide a significant planning and evaluation tool when used by an interdisciplinary team of archaeologists, engineers, and scientists.

27. The suggested logic-based, decay model can be significantly improved and

enhanced through a series of small scale, single investigator or small interdisciplinary research team research projects designed to answer specific questions or develop technologies that could be applied to a specific archaeological site protection project. Budget estimates for these type research projects should range from $30,000 to $50,000 per year. Specific criteria for project support should be based on the potential benefit/cost ratio rather than on the basic research potential of a proposed project. Many of these studies could be funded in association with a major project being carried out in a Corps District, on an as needed basis. However, some projects, due to their generic nature, should be funded through the Army Research programs.

28. A significant accomplishment of the workshop was the open exchange of interdisciplinary ideas and scientific thought about the overall problem of archaeological site decay and preservation. As the workshop progressed, new concepts that had never been applied to the problem of site decay and preservation developed. Concepts such as micro-soil mechanics, micro-biochemical processes, applications of natural and man-made analogs, and socio-geomorphology developed during the workshop. The workshop was an excellent starting point for the development of a cost effective archaeological site decay and preservation model.

Recommendations and Research Needs

29. The successful interchange of theories, technologies and techniques seen during the workshop strongly suggests that an "Interdisciplinary Workshop on Archaeological Site Decay and Preservation" should be held on a regular schedule. Future workshops have the potential to enhance and develop new approaches to our knowledge of archaeological site decay and preservation.

30. Research needs and problem statements concerning the physical, biological and chemical processes affecting archaeological site decay were defined by the workshop participants. These needs were divided into five categories: General, Cultural, Physical, Biological and Chemical for organizational purposes, although much of the research should be carried out by an interdisciplinary team.

General

31. Research needs in this category concentrate on the interdisciplinary interactions between the components within a site, the archaeological site survey technology, and the physical, biological and chemical processes active at a site. Specific research project

statements are given below:

a. Site decay rates for each individual component found in an archaeological site need to be determined as a function of the physical, biological and chemical conditions. If decay rates are known, it would be possible to determine the age and decay history of an archaeological site or determine the impact of an environmental change on a buried site. This information would be used to determine whether a generalized decay model can be constructed as an average rate model.

b. Determine the natural changes that take place in an archaeological site as a function of time. These results would provide a base-line for evaluating the impact of engineered site burial.

c. Determine the survival and recoverability of archaeological site components. This study would "create" a test site, allow the site to age and then excavate it in a sequential manner to determine changes with time and impact of excavation of the site components.

d. A field investigation to determine the significance of erosional and mass wasting processes compared to vandalism of sites.

e. Re-evaluate and re-excavate a site situated in a destructive environment, such as a shoreline zone, that has been buried for preservation. Detailed comparisons of the initial excavation results and the results of the re-excavation will provide data on the success of burial in these types of environments.

f. Generate a formal decision-tree, flow-chart or computer model designed to guide the site protection decision making process. This process would start with a given set of conditions determined for a site under study, follow the qualitative site decay model identified in this workshop, and conclude with a cost effective decision of the most effective alternative for site preservation. This project would probably be most economical if it is carried out for a specific region or large project rather than for the Nation as a whole.

Physical

33. The primary physical process research needs identified by the workshop concentrate on the mechanical and climatological influences of burial on site components. Specific research programs identified in this category are listed below:

a. A field investigation of the physical and chemical changes that occur in buried soils would provide information on the influence of burial. This investigation could be carried out using existing engineered fills through a comparison of buried soil below a fill and unburied soil next to the fill site.

b. A small scale field investigation of the compressive and differential stresses induced on buried site components. Laboratory investigations of the "micro-stress" conditions in soil samples may provide data that could be used

to develop a quantitative technique to predict these stresses.

c. Laboratory testing of the differential stress conditions needed to break or crush bone, shell, pottery, and other brittle site components.

d. Field investigation, using soil geomorphic techniques to determine the amount of site disturbance and mixing due to periglacial, expansive soil, and mass wasting processes.

e. Determine the influence of cyclic wetting and drying and heating and cooling processes on the preservation of plant remains.

f. Determine the relationship between depth of burial, type of material, and seasonal fluctuations in soil moisture content, soil movement, temperature and other climatological factors.

Biological

34. Biological problems identified in the workshop are associated with the control of burrowing macro-organisms and the relationship between micro-organisms and the soil environment. Specific research programs are:

a. A field and literature investigation of the rate and types of burrowing animals in existing burials, including landfills, engineered fills, dams, and other elevated earth structures.

b. Investigate potential site capping materials for buried sites and evaluate the response of burrowing animals.

c. Investigate the micro-environment within a soil and its community of micro-organisms. Determine the influence of soil texture, moisture, temperature, and other factors on community populations.

Chemical

35. Chemical concerns expressed by the participants at the workshop concentrated on the effect of environmental changes, be they natural or due to burial, on the isotopic content, which affects dating techniques, and on plant and other organic site components. Recommended research on the chemical aspects of site decay include:

a. Investigate the effect of inundation of a site on the quality of datable materials, and the kinds of chemical alteration introduced by either inundation or a rising ground-water level. The Lubbock Lake site was proposed as a test site because the level of pre-flooding research on the site's stratigraphy, chronometry and isotopic composition is exceptionally well documented.

b. Chemical and geochemical investigations to be carried out in cooperation with

physical studies of the ground-water system, of induced changes brought about by changes in the quality and quantity of the ground water and wetting and drying cycles.

c. Investigate the feasibility of using a suite of isotopes, with different half-lives, to determine the history of chemical alteration of archaeological sites. This technique may provide a mechanism to determine the natural alteration as well as a Man induced alteration of a site.

d. Investigate the effect of burial on the vertical distribution, type and concentration of isotopic species. This study should investigate both burial material (acid vs. basic soils, permeable vs. impermeable soils, etc.) and depth of burial.

e. Investigate the effect of carbonates (alkaline soils) on the preservation or decay of plant remains and other site components. An apparent conflict exists between archaeobotany and soil science, with carbonates reported to be detrimental to plant remains, and preservers of humic (organic) soil horizons.

f. The basic understanding of the organic chemical reactions and processes of plant decay are not well known.

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APPENDIX A: INTERDISCIPLINARY BIBLIOGRAPHY ON THE CULTURAL, PHYSICAL, CHEMICAL, AND BIOLOGICAL FACTORS AFFECTING ARCHAEOLOGICAL SITES

Introduction

1. The accompanying bibliography was originally intended to serve as a research guide for the participants of the Archaeological Site Decay Model Workshop, held in College Station, Texas on May 27-29, 1987. Since then, the original bibliography has been expanded to include references used by the participants in their respective papers and additional references located since. The material listed is multidisciplinary in content, with sources catalogued into five major groups: Cultural, Physical, Chemical, Biological, and Archaeochronological.

2. The Cultural division includes sources on anthropological method and theory; excavation methodology; site stratigraphy and site geomorphology; archaeological site components, particularly human, fauna and flora remains; and paleoenvironments, including Man's interaction with the environment through time.

3. The Physical division includes sources on physical processes that have or may have an impact on an archaeological site's formation and preservation, including climate, and active geomorphic and soil formation processes.

4. The Chemical category covers material on the chemical processes affecting the archaeological site and its associated artifacts. This includes, among others, soil physico-chemistry, metal corrosion, soil-bone interaction and bone preservation, and water's deteriorating effect on various substances.

5. The Biological category covers all biological agents of site disturbance, namely, plants and animals, including human intrusion.

6. The Archaeochronological category includes all dating techniques, and their limitations, of use to the archaeologist. The term archaeochronology is distinguished from geochronology to include only those dating methods useful to date Quaternary-aged deposits (approximately 2 million years old). Dating methods used by geologists to date three-billion-years-old rocks, such as uranium or thorium decay series, and the rubidium-strontium method, are therefore omitted.

7. Finally, several references have been catalogued as "general" because they touch on many of the subjects of interest listed above. These are usually textbooks that deal with, for example, the whole range of geomorphic processes, or most types of site disturbance processes. Their importance as introductory reading should not be overlooked.

Methodology

8. The compilation of sources involved the following procedure:

   a. An initial literature search was made at the Texas A&M University Sterling C. Evans Library. A large percentage of the sources were collected from the bibliographies and lists of references of selected books and papers. This method was continued until a cross-examination of bibliographies yielded repeating sources.

   b. Computer searches were made which access the following indexes or databases:
      GEOREF, a comprehensive geosciences reference listing;
      NTIS, which contains government funded research reports;
      AHCI, Arts and Humanities Citation Index;
      DISS, Dissertation Abstracts;
      Info-Tract; and
      America - History & Life.

9. Each computer search involved the roots of the following set of concepts, or key words: archaeology and archeology, prehistory, artifact and artefact, geoarchaeology, disturbance, decay, destruction, deterioration, degradation, wear, threatened, preservation, conservation, protection, salvage, and maintenance.

Style

10. The bibliographic listing is given alphabetically by senior author using the reference style of The Bulletin of the Association of Engineering Geologists. The major divisions and key words are listed following each bibliographic citation.

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